VOLUME XI. SECOND SERIES NUMBER 6

THE PHYSICAL REVIEW

Physics Library
QC
1
P58
v.11
no.6

A JOURNAL OF EXPERIMENTAL AND THEORETICAL PHYSICS

CONDUCTED BY

THE AMERICAN PHYSICAL SOCIETY

BOARD OF EDITORS

FREDERICK BEDELL, Managing Editor

E. P. LEWIS	N. E. DORSEY	G. K. BURGESS
W. C. SABINE	WM. DUANE	A. D. COLE
A. TROWBRIDGE	O. M. STEWART	A. C. LUNN

JUNE, 1918

A Preliminary Study of the Luminescence of the Uranyl Salts under Cathode Ray Excitation. FRANCES G. WICK and LOUISE S. McDOWELL 421

Note on the Grating Space of Calcite and the X-Ray Spectrum of Gallium. ARTHUR H. COMPTON 430

Characteristic X-Ray Emission as a Function of the Applied Voltage. BERGEN DAVIS 433

On the Formation of Negatively Electrified Rain Drops. FERNANDO SANFORD 445

The Air-Damped Vibrating System: Theoretical Calibration of the Condenser Transmitter. I. B. CRANDALL 449

Wave-Lengths of the Tungsten X-Ray Spectrum. ELMER DERSHEM 461

American Physical Society. 477

Minutes of the Ninety-Third Meeting; Minutes of the Ninety-Fourth Meeting; Thermo-couples for Student Use in Calorimetric Work, *Ralph S. Minor*; An Harmonic Synthesizer Having Components of Incommensurable Period and any Desired Decrement, *William J. Raymond*; Variation of Velocity of Waves due to Motion of the Source, *Dimitrios Aliotis*; Photographs of an Aurora Model, *C. C. Trowbridge*; On the Observation of the Apparent Focus of Aurora Streamers, *C. C. Trowbridge*; Meteor Train Spectra and Probable Erroneous Conclusions of the Observers, *C. C. Trowbridge*; The Photo-Luminescence and Kathode-Luminescence of Calcite, *E. L. Nichols, H. L. Howes and D. T. Wilber*; A Method for the Quantitative Study of Gases in Metals, *H. M. Ryder*; The Resonance and Ionization Potentials for Electrons in Thallium Vapor, *Paul D. Foote and Fred L. Mohler*; Electronic Frequency and Atomic Number, *Paul D. Foote*; On the Relation between the *K* X-Ray Series and the Atomic Numbers of the Chemical Elements, *William Duane and Kang-Fuh Hu*; On the Critical Absorption and Characteristic Emission X-Ray Frequencies, *William Duane and Kang-Fuh Hu*; The Relation between the General X-Radiation and the Atomic Number of the Target, *William Duane and Tahei Shimizu*; The Influence of Amalgamation Variables upon the Mercury Content and the Crushing Strength of a Dental Amalgam, *Arthur W. Gray and Paris T. Carlisle, Fourth*; Increase in Length of Life of Tribonium Confusum, Due to X-Rays, *Wheeler P. Davey*; The Spectral Photoelectric Sensitivity of Molybdenite, *W. W. Coblentz, M. B. Long and H. Kahler*; The Influence of Amplitude and of Electromagnetic Driving on the Frequency of Tuning Forks, *Dayton C. Miller*; The Law of Symmetry of the Visibility Function, *Irwin G. Priest*; A Precision Method for Producing Artificial Daylight, *Irwin G. Priest*; Transparency of Certain Carbon Compounds to Waves of Great Length, *F. P. Hollnagel*; Some Preliminary Results in a Determination of the Maximum Emission Velocity of the Photoelectrons from Metals at X-Ray Frequencies, *Kang-Fuh Hu*.

Erratum 508

Index 509

PUBLISHED BY

THE AMERICAN PHYSICAL SOCIETY

LANCASTER, PA., AND ITHACA, N. Y.

Entered at the post-office, at Lancaster, Pa., as second class matter

UNIVERSITY OF MICHIGAN LIBRARIES

THE AMERICAN PHYSICAL SOCIETY

OFFICERS OF THE SOCIETY

President:	H. A. BUMSTEAD	Yale University, New Haven, Conn.
Vice-President:	J. S. AMES	Johns Hopkins University, Baltimore, Md.
Secretary:	D. C. MILLER	Case School of Applied Science, Cleveland, Ohio
Treasurer:	G. B. PEGRAM	Columbia University, New York City
Editor:	F. BEDELL	Cornell University, Ithaca, N. Y.
Local Secretary for the Pacific Coast:	E. P. LEWIS	University of California, Berkeley, Cal.

The Council of the Society consists of the president, vice-president, secretary, treasurer, all living Past Presidents and eight elected members as follows:

Past Presidents: A. A. Michelson, A. G. Webster, Carl Barus, E. L. Nichols, Henry Crew, W. F. Magie, Ernest Merritt, R. A. Millikan.

Elected Members: C. E. Mendenhall, G. W. Stewart; Irving Langmuir, G. B. Pegram; G. O. Squier, H. A. Wilson; A. L. Day, G. F. Hull.

THE PHYSICAL REVIEW

Annual Subscription, throughout the Postal Union, $6.00
Single Copies, postpaid, $ .60

THE PHYSICAL REVIEW is conducted by a BOARD OF EDITORS, named on the outside cover

Subscriptions should be sent to THE PHYSICAL REVIEW, *41 North Queen Street, Lancaster, Pa., or Ithaca, N. Y.*

Two volumes of THE PHYSICAL REVIEW are published annually, these volumes beginning in January and July, respectively, and containing six numbers each.

A limited number of complete sets of the REVIEW, both First and Second Series, will be supplied at the price of $3.00 per volume for all volumes, carriage extra. When they can be furnished without breaking a set, separate back volumes will be supplied at the same price, and single back numbers will be mailed to any address in the Postal Union at the price of $.60 per copy.

Back numbers will be furnished to members at a discount of ten per cent., provided a statement of membership accompanies the order. When a member's name has been dropped from the mailing list of the Review on account of non-payment of dues, his name will be restored to the mailing list when dues are paid; and any numbers that he has failed to receive in the interim will be furnished without cost upon application to the Review. *All complaints for failure to receive the Review should be addressed to the Review and not to any officer of the Society.*

First Series. From July 1, 1893, to January 1, 1913, the REVIEW was conducted by Edward L. Nichols, Ernest Merritt and Frederick Bedell, with the financial support of Cornell University. During this period thirty-five volumes were issued, constituting the First Series. The first four volumes of the First Series were issued annually; subsequent volumes were issued semi-annually.

Second Series. On January first, 1913, the Review was transferred to the American Physical Society. A second series was then begun, the January, 1913, number being designated Volume I., Number 1, Second Series. (An announcement of this transfer will be found on the first page of the new series.)

For advertising rates, address THE PHYSICAL REVIEW, *Ithaca, N. Y.* Change of copy in standing advertisements should be sent direct to the printers, THE NEW ERA PRINTING CO., *Lancaster, Pa.*

Contributors to the REVIEW are referred to page two of the advertisements for further information.

Permission is given to republish any article appearing in the REVIEW, provided proper credit is given.

Address Correspondence to

THE PHYSICAL REVIEW, ITHACA, N. Y.

Second Series. *June, 1918.* *Vol. XI., No. 6*

THE

PHYSICAL REVIEW.

A PRELIMINARY STUDY OF THE LUMINESCENCE OF THE URANYL SALTS UNDER CATHODE RAY EXCITATION.

By Frances G. Wick and Louise S. McDowell.

THE luminescence of the uranyl salts, including the fluorescence and a short-time phosphorescence, has been extensively investigated. The fluorescence spectrum consists of a number of more or less sharply defined bands forming a series in which the frequency interval is practically constant. The bands of the absorption spectrum form a similar series with a slightly shorter interval, and in the violet region of the spectrum the two sets of bands overlap.

The fluorescence bands in the violet region are less sharp and the measured frequency interval is slightly less than the usual interval for the series. As the position of the absorption bands is very nearly coincident with that of the fluorescence bands it seemed probable that the change in the interval was due to the fact that a portion of each fluorescence band under light excitation was cut off by absorption so that the observed position of the crest differed slightly from the true position. To determine whether any such effect occurs the writers undertook, at the suggestion of Professor E. L. Nichols, a comparative study of the fluorescence of the uranyl salts under excitation by light and by cathode rays, since in the latter case the effect is only upon the surface and there is no absorption to shift the apparent position of the maximum.

In the course of the investigation there was discovered a long-time phosphorescence of the uranyl salts under cathode-ray excitation, at liquid-air temperature. Since the phosphorescence of these salts hitherto observed had been of much shorter duration, it seemed important to investigate further this long-time phosphorescence.

Fluorescence.

Since the variation from the uniform interval in the violet region of the spectrum is small it was necessary that any comparison of the posi-

tion of bands under excitation by light and by cathode rays should be made by observations upon spectra in which the bands are narrow and sharply defined. At low temperatures the fluorescence bands of all the uranyl salts are resolved into groups of bands comparable in width with the lines of a gaseous spectrum. In the chlorides, however, the bands are resolved at room temperature and it was hoped that these salts might be used, to avoid the experimental difficulties involved in the use of liquid air. Tests of rubidium, potassium, cæsium, and ammonium chlorides showed in no case sufficient fluorescence under cathode-ray excitation to be observable in the spectroscope. It was necessary, therefore, to use other crystals in which the fluorescence was brighter, but the bands of which were resolved only at liquid-air temperatures.

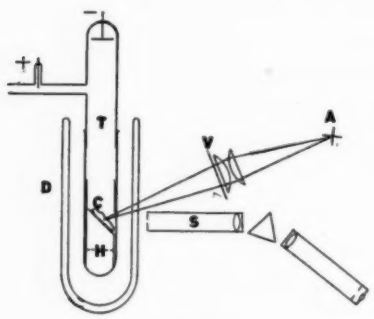


Fig. 1.

The arrangement of apparatus is shown in Fig. 1. The crystal was placed in a cathode-ray tube, *T*, in such a position that the direction of bombardment made an angle of about 45° with the surface of the crystal. To cut off stray light, the tube was surrounded with black paper, save for an opening about fifteen millimeters square in front of the crystal, *C*. To facilitate the removal of the crystal, made necessary by the large number of salts to be examined and by their instability, the specimen was fastened by fine wires to a cylindrical aluminum holder, *H*. The tube was then immersed in liquid air, in an unsilvered Dewar cylinder, *D*, and exhausted by a Gaede rotary pump. An arc light, *A*, was so placed that the crystal could be excited alternately by cathode rays and by light from the arc passed through violet glass, *V*. As a result of observations upon a large number of crystals the salts tested were grouped under three heads:

(*a*) Salts showing practically no fluorescence under cathode-ray excitation.

The chlorides.

(*b*) Salts too wet to allow the attainment of a sufficiently high vacuum or giving a deposit which coated the glass and prevented observation.

1. Uranyl nitrate (hexahydrate).
2. Uranyl nitrate (crystal plates).
3. Uranyl-ammonium sulphate (with two molecules of water).

4. Uranyl-sodium sulphate (with two molecules of water).
5. Uranyl-rubidium sulphate (with two molecules of water).

(*c*) Salts of bright fluorescence and relative stability.

1. Uranyl-potassium nitrate, $K_2UO_2(NO_3)_4$ (crystallized from 10–30 per cent. nitric acid).
2. Uranyl-potassium nitrate, $K_2UO_2(NO_3)_4$ (long crystals from 2–3 per cent. nitric acid).
3. Uranyl-potassium nitrate, $KUO_2(NO_3)_3$ (water form).
4. Uranyl-potassium nitrate, $KUO_2(NO_3)_3$ (anhydrous).
5. Uranyl-potassium sulphate.
6. Uranyl-potassium sulphate (with two molecules of water).

Of the salts in the last group the uranyl-potassium sulphate, No. 5, was the most brilliantly fluorescent and was therefore selected for further study. The fluorescence spectrum of the crystal was first observed under alternate excitation from the two sources following in immediate succession. The pointer in the focal plane of the eye-piece was set upon a given band under light excitation and, without change in the position of the pointer, the crystal was excited by cathode rays. Observations of the green bands showed no shift in the position of the lines with a change in the excitation, but the first violet band, the only one observable, presented a markedly different appearance. Under light excitation it looked like a somewhat broad, faint band, imperfectly resolved. Under cathode-ray excitation, it showed a group of lines exactly similar to the other groups of the series, and the brightest line in the group was found to be of somewhat shorter wave-length than the crest of the arc-excited band.

First Determination.

Under Arc Excitation.			Under Cathode-Ray Excitation.		
λ.	$1/\lambda \times 10^3$.	Interval.	λ.	$1/\lambda \times 10^3$.	Interval.
.5870	1703.6		.5870	1703.6	
		82.1			80.5
.5600	1785.7		.5605	1784.1	
		87.0			86.8
.5340	1872.7		.5345	1870.9	
		84.2			84.9
.5110	1956.9		.5113	1955.8	
		75.6			85.8
.4920	2032.5		.4898	2041.6	

Second Determination.

			.5890	1697.1	
					86.4
.5600	1785.7		.5605	1784.1	
		85.9			86.8
.5345	1871.6		.5345	1870.9	
		82.6			83.4
.5117	1954.2		.5117	1954.3	
		76.3			81.5
.4925	2030.5		.4912	2035.8	

An independent determination of the wave-length of the brightest line in each group which was sufficiently bright for accurate settings was made with each source of excitation. The results obtained are shown in Table I. The intervals calculated from the observations are in terms of frequency, in the unit $1/\lambda \times 10^3$.

Under cathode-ray excitation the interval in the violet end of the spectrum is practically equal to the other intervals of the series. Under light excitation, as has previously been observed, this interval is less. It appears therefore that the inequality in the interval and the change in the appearance of this violet band under light excitation are due to absorption.

PHOSPHORESCENCE.

The short-time phosphorescence produced in the uranyl salts under the action of violet light at liquid-air temperatures has been investigated by Nichols and Howes.[1] All the uranyl salts examined possess the same type of phosphorescence under light excitation. The intensity falls to one thousandth of its initial value in .0035 second. Under X-ray excitation, some of the salts exhibit a phosphorescence of greater intensity and longer duration permitting observation for 20 or 30 seconds.[2] The discovery of a phosphorescence under cathode rays of much longer duration than either of these opened a new field for investigation. Only a preliminary study of the phenomenon is included in this paper. The original observation of this phosphorescence was made during the study of the fluorescence, in which the crystal had been alternately excited by light from a carbon arc and by cathode rays. At the time it was not apparent whether one or both of these sources of excitation produced the phosphorescence. Further observations showed that the long-time phosphorescence was produced only by cathode rays, after prolonged excitation, at liquid-air temperature.

An examination was made of all the uranyl salts in group *C*, large, well-formed crystals of which had been made by D. T. Wilber. They were found to exhibit phosphorescence in varying degrees. Some showed no phosphorescence at all. The following salts were the brightest.

1. $KUO_2(NO_3)_3$, crystallized from acid without water of crystallization.

2. $K_2UO_2(NO_3)_4$, discovered by D. T. Wilber and crystallizing in two different forms. The first, form *A*, was crystallized from a 10–30 per cent. solution of nitric acid and the second, form *B*, from a 2–3 per cent. solution. Although the crystallographic system is identical, form *A*

[1] Nichols and Howes, PHYS. REV. (2), IX., p. 292.

[2] Frances G. Wick, PHYS. REV. (2), V., p. 418.

crystallizes in short, thick crystals and form *B* in long, slender crystals. There appeared to be a slight difference in the phosphorescence of the two forms. It is possible, however, that the difference observed might have been due to some variation in the conditions under which the phosphorescence was produced.

3. $K_2UO_2(SO_4)_2 \cdot 2H_2O$.

4. $K_2UO_2(SO_4)_2$.

5. Uranyl nitrate, plate crystals.

The specimens finally selected for further study were No. 2, forms *A* and *B*, and No. 4, hereafter referred to as Specimens 1, 2, and 3.

The work of Nichols[1] had shown the spectrum of the short-time phosphorescence of the uranyl salts to be identical with the fluorescence spectrum. Observations were made to determine whether the same relation holds for the long-time phosphorescence. The pointer of the eyepiece was set upon the brightest line of each of a number of bands in the fluorescence spectrum. After a short interval to rest the eye of the observer the crystal was again excited and the phosphorescence spectrum observed. In every instance the pointer was found to be exactly upon the corresponding line of the phosphorescence spectrum. Independent determinations of the wave-lengths of lines of the fluorescence and phosphorescence spectra were also made and the two found to be identical. The latter measurements were made possible by the brilliance and long duration of the phosphorescence which allowed ample time to make settings upon the brighter lines of the spectrum.

The decay curves for the short-time phosphorescence had been found by Nichols and Howes[2] to differ from the usual type in that, of the two processes of decay, the second was more rapid than the first. Observations were made of the decay of the long-time phosphorescence of Specimens 1, 2, and 3. The arrangement of apparatus is shown in Fig. 2.

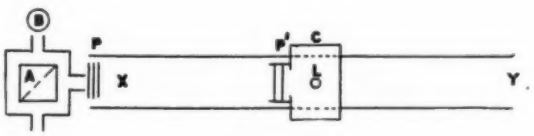


Fig. 2.

A Lummer-Brodhun cube, *A*, was placed at one end of a track, *XY*, about three and one half meters long. The crystal, *B*, was placed opposite one face of the cube. The comparison source, *L*, was a 5-volt tungsten lamp placed in parallel with a suitable rheostat upon a 55-volt

[1] Nichols, Proceedings of National Academy of Sciences, Vol. II., p. 328.

[2] Nichols and Howes, PHYS. REV., l. c.

circuit. The lamp was mounted in a carriage, C, running on the track, XY, on which at intervals of about twenty-five centimeters stops were placed. Green, blue, and ground glass absorption plates, P and P', were inserted to obtain a comparison source of the proper color and intensity. A chronograph was used to record the time. The zero of time was in every instance recorded when the primary circuit of the induction coil was broken. When the intensity of phosphorescence matched that of the source in the first possible position the time was again recorded and the carriage moved to the next stop and allowed to remain until a match was obtained as before. This procedure was continued until the phosphorescence was too faint to observe or until the end of the track was reached.

The interpretation of the results was difficult since the instability of the crystals rendered uncertain both the control of the vacuum and the maintenance of the crystal surface unchanged during prolonged bombardment. The general shape of the decay curve after long excitation is shown in Fig. 3. The curves are plotted in the customary way with

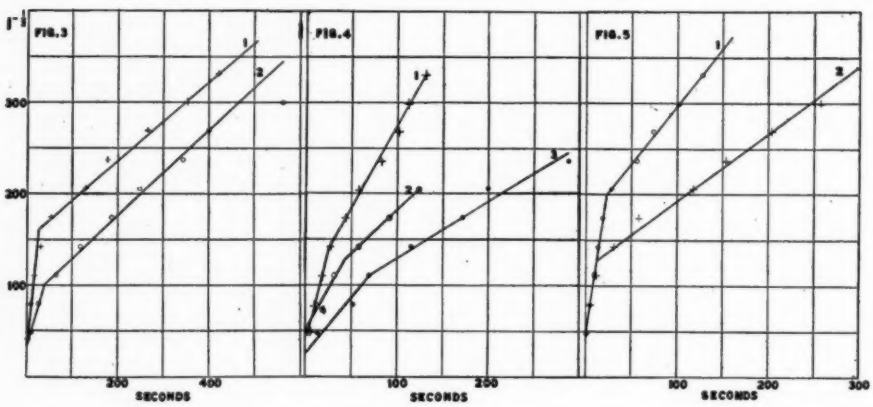


Fig. 3. Fig. 4. Fig. 5.

FIG. 3. Curves showing long-time decay. Specimen No. 1. Time of excitation 20 seconds, Interval between excitations 600 seconds.

FIG. 4. Curves showing decay after different lengths of excitation. Specimen No. 1. Curve 1. long excitation; Curve 2, medium excitation; Curve 3, short excitation.

FIG. 5. Curves showing change in time of beginning of second process. Specimen No. 2. Time of excitation unknown.

the reciprocal of the square root of the intensity as a function of the time. This decay curve is of the usual type, consisting of two linear processes of which the first is the more rapid. Under different conditions phosphorescence was observed to last from less than a minute to ten or fifteen minutes. The exact form of the curve varied with the time of excitation,

the voltage applied, and the vacuum. The time of decay was found to increase with the time of excitation as shown in Fig. 4, but the initial brightness changed relatively little. There was some evidence to indicate that under similar conditions of vacuum the rate of the first process

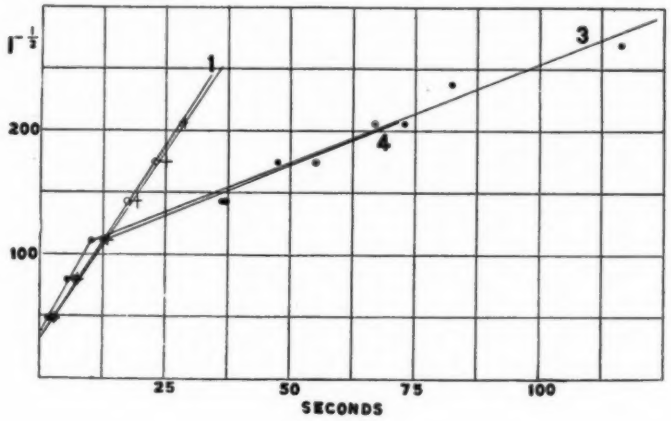


Fig. 6.

Curves showing effect of varying length of excitation. Specimen No. 3. Curves 1 and 2, time of excitation 20 seconds; Curve 3, time of excitation 40 seconds; Curve 4, time of excitation 80 seconds.

remained practically unchanged for varying times of excitation but that the second process began sooner for the longer excitation as shown in Figs. 5 and 6. In Fig. 6, Curves 1 and 2, obtained by a short-time excitation, show only the first process, whereas Curves 3 and 4, obtained by excitations of 40 and 80 seconds respectively, indicate that a state of saturation had been reached such that added excitation produced no change in the phosphorescence.

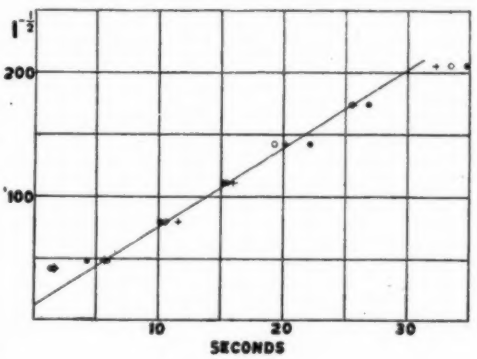


Fig. 7.

Curves showing repetition after short excitation. Specimen No. 1. Time of excitation, 20 seconds. Intervals between excitations 63 seconds, 67 seconds.

As has been stated the initial brightness and rate of decay were found to depend also upon the strength of the bombardment, as varied by the pressure in the tube and by the voltage applied to the induction coil. The curves of Fig. 3, for example, were obtained with a relatively high vacuum whereas those of Fig. 7

were obtained with a very low vacuum, so that the decay was comparatively rapid and there was only a suggestion of the beginning of the second process in the position of the last point observed. Slight changes in temperature, such as were produced when the liquid air fell below the line of the crystal were found also to produce changes in the initial brightness and rate of decay.

To determine whether the excitation produced any secondary change in the crystal which persisted after the phosphorescence had disappeared, so that there would be a progressive building up of the phosphorescence, excitations were made of equal length, repeated at as nearly equal intervals as decay observations permitted. Fig. 7 shows that at a fairly low cathode vacuum an excitation of 20 seconds repeated at approximately one-minute intervals produced identical decay curves. The same effect is shown in Fig. 8 for a much longer period of decay. When the time between excitations was short as compared to the time and strength of excitation there appeared to be a progressive change as indicated in Fig. 9.

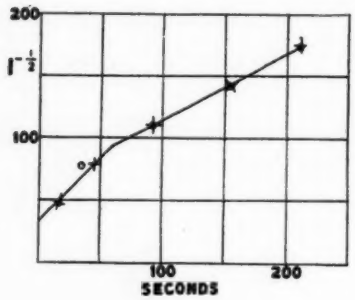


Fig. 8.

Curves showing repetition after long excitation. Specimen No. 1.

As a result of this investigation three definite conclusions may be drawn:

1. The irregularities in the fluorescence spectrum of the uranyl salts under light excitation are due to absorption.

2. The spectrum of the long-time phosphorescence produced by cathode-ray excitation at liquid-air temperatures is identical with the fluorescence spectrum.

3. The decay curve is of the type usual to phosphorescence of long duration in which the second process is less rapid than the first.

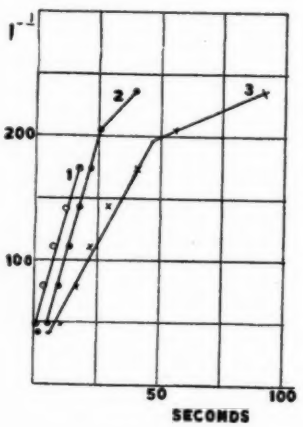


Fig. 9.

Curves showing effect of previous excitation. Specimen No. 2. Time of excitation, 20 seconds.

No satisfactory conclusions as to the effect of variations in time of exposure and strength of cathode-ray bombardment, or the influence of previous excitation can be drawn until conditions can

be more exactly controlled. It is hoped with further study to obtain results capable of more exact interpretation.

The investigation was carried on at Cornell University during the summer of 1917, and the writers wish to express their sincere thanks to Professor E. L. Nichols for his kindness in making the work possible.

VASSAR COLLEGE,
WELLESLEY COLLEGE.

NOTE ON THE GRATING SPACE OF CALCITE AND THE X-RAY SPECTRUM OF GALLIUM.

BY ARTHUR H. COMPTON.

IN a recent number of this journal[1] Uhler and Cooksey have described a method of measuring the angle of reflection of X-ray spectrum lines which seems to be remarkably free from systematic errors, and capable of high precision. They applied their method to the determination of the angle of reflection of the characteristic K lines of gallium from a crystal of calcite. In calculating the wave-length of these rays they obtained the grating space of calcite by comparing it experimentally with the grating space of rock-salt, which can be determined in terms of the known crystal structure. In making this comparison, however, they determined the angles of reflection from rock-salt by an "old" method which, as they point out, is liable to introduce appreciable errors. Their determination of the grating space of calcite and hence also of the wave-length of the characteristic X-rays from gallium, is therefore no more accurate than the measurements made by the "old" method which they criticize.

The reason assigned by Uhler and Cooksey for making this experimental determination of the grating space is "because a sufficiently satisfactory reduction factor [the ratio of the grating space of calcite to that of rock-salt] if present in the literature of the subject, has escaped our notice." It should be noted that the grating space in the case of calcite may be calculated from the known crystal structure as well as in the case of rock-salt. The formula to be used is given by W. H. Bragg[2] and the writer[3] as,

$$(1) \qquad d_1 = \left(\frac{1}{2} \frac{M_1}{\rho_1 N \phi(\beta_1)} \right)^{\frac{1}{3}},$$

where M_1 is the molecular weight of $CaCO_3$, ρ_1 is the density of the calcite crystal, N is the number of molecules per gram molecule, and $\phi(\beta_1)$ is the volume of a rhombohedron the distance between whose opposite faces is unity, and the angle between whose edges is β_1. This function is[4]

[1] PHYS. REV., 10, 645, 1917.

[2] W. H. Bragg, Proc. Roy. Soc. A., 89, 468 (1914). "X-rays and Crystal Structure," p. 112.

[3] A. H. Compton, PHYS. REV., 7, 655 (1916).

[4] A. H. Compton, *loc. cit.* Professor Bragg uses the value $\phi(\beta) = 1.08$, which makes his value of d for calcite differ appreciably from that here obtained.

$$\phi(\beta_1) = \frac{(1 + \cos \beta_1)^2}{\sin \beta_1 (1 + 2 \cos \beta_1)}.$$

For calcite $\beta_1 = 101° 55'$[1] which makes $\phi(\beta_1) = 1.0963$.

The corresponding expression for the grating space of rock-salt is

$$d_2 = \left(\frac{1}{2} \frac{M_2}{\rho_2 N}\right)^{\frac{1}{3}}, \tag{2}$$

the subscripts 2 indicating that the molecular weight and density are those corresponding to rock-salt. The reduction factor sought by Uhler and Cooksey is, therefore,

$$R = \frac{d_1}{d_2} = \left(\frac{M_1 \rho_2}{M_2 \rho_1 \phi(\beta_1)}\right)^{\frac{1}{3}}, \tag{3}$$

which gives the ratio of the grating space of calcite to that of rock-salt.

Bragg's expression[2] is not dependent upon the details of the arrangement of the atoms in the calcite crystal. It expresses only the fact that each elementary rhombohedron contains half a molecule of $CaCO_3$. The uncertainty of the applicability of this formula is thus no greater than in the corresponding case of rock-salt. In fact the calculated value of the grating space of calcite is probably the more accurate, since this crystal is more perfect and is less apt to contain inclusions than is rock-salt.

Substituting in formula (1) the values:

$$M_1 = 100.075,^3$$

$$\rho_1 = 2.7116 \text{ g. cm.}^{-3},^4$$

$$N = 6.062 \times 10^{23} \text{ per gram molecule},^5$$

$$\phi(\beta_1) = 1.0963,$$

we find for the grating space of calcite,

$$d = 3.0281 \times 10^{-8} \text{ cm.}$$

The greatest uncertainty in this value is due to N, whose probable error is $\pm$ 0.1 per cent. Since N occurs in the 1/3 power, the probable error in d is about .033 per cent. Thus the grating space of calcite is

$$d_1 = 3.0281 \pm .0010 \times 10^{-8} \text{ cm.}$$

The value determined by Uhler and Cooksey by comparison with rock-

[1] Calculated from Dana's value of 74°55′ for the dihedral angle.

[2] W. H. Bragg and W. L. Bragg, "X-rays and Crystal Structure," p. 110.

[3] International Atomic Weights 1917.

[4] A. H. Compton, loc. cit.

[5] R. A. Millikan, Phil. Mag., 34, 13 (1917).

salt, using $d_2 = 2.814 \times 10^{-8}$ cm. is $d_1 = 3.0307 \times 10^{-8}$ cm. Gorton[1] has determined the grating space of calcite by a similar comparison method, using the same value of d_2, and obtains $d_1 = 3.028 \times 10^{-8}$ cm., which agrees absolutely with the theoretical value. Millikan[2] gives for the grating space of calcite the value $(3.030 \pm .001) \times 10^{-8}$ cm., calculated by D. L. Webster[3] using Millikan's value of e. In this calculation Webster has made use of Bragg's value of $\phi(\beta_1) = 1.08$ instead of the true value 1.0963, which accounts for the difference between his value and that here given.

The wave-lengths of the characteristic X-rays from gallium given by Uhler and Cooksey require revision because of this error in their determination of the grating space of calcite. Their determinations of the angles of reflection from calcite were verified by their "new" method, and hence are not subject to the errors introduced when they determined the angles from rock-salt by their "old" method. Their values for the angles of reflection from calcite may thus be accepted without discount. Their values for the wave-length are given in the following table together with the corrected values using the value of $d_1 = 3.0281 \pm .0010 \times 10^{-8}$ cm.

Line.	Reflection Angle from Calcite.	$\lambda \times 10^8$ cm. Uhler & Cooksey.	$\lambda \times 10^8$ cm. Corrected.
α_2.....	12° 47′ 15″ ± 2″	1.34161 ± .00004	1.34046 ± .00045
α_1.....	12° 45′ 5″ ± 2″	1.33785 ± .00004	1.33673 ± .00044
β_1.....	11° 28′ 30″ ± 2″	1.25691 ± .00000	1.20482 ± .00041

The probable error in the wave-length is estimated by Uhler and Cooksey on the basis of their probable error in measuring the angle. It should be noted that a much larger error in the wave-length is introduced by the uncertainty of the grating space.

RESEARCH LABORATORY,
WESTINGHOUSE LAMP COMPANY,
January 22, 1918.

[1] W. S. Gorton, PHYS. REV., 7, 209 (1916).
[2] R. A. Millikan, loc. cit., p. 16
[3] D. L. Webster, PHYS. REV., 7, 607 (1916).

CHARACTERISTIC X-RAY EMISSION AS A FUNCTION OF THE APPLIED VOLTAGE.

BY BERGEN DAVIS.

RECENT experiments of D. L. Webster[1] show that the energy of emission of characteristic (line) radiation from a rhodium target increases rapidly as the voltage applied to the Coolidge X-ray tube is increased. The radiation is not produced at all unless the voltage is greater than a minimum V_0. This minimum voltage is slightly greater than that corresponding by the quantum relation to the frequency of the β line (K-radiation). This law is undoubtedly true also for the characteristic X-ray emission from other elements.

It may be of some interest and value to investigate how this emission should depend on the voltage from a consideration of well-established physical facts. The following facts relating to the problem may be regarded as established by experiment.

(*a*) The characteristic line emission is zero for all voltages less than a critical voltage V_0.

(*b*) The voltage V_0 at which the characteristic radiation is produced is that corresponding by the quantum relation, $V_0 e = hn$, to a frequency slightly greater than that of the K_β radiation of the element.

(*c*) At voltages equal to and greater than V_0 both the α and β lines of the K radiation are emitted. These two lines increase rapidly in intensity with the voltage, their ratios remaining approximately constant.

(*d*) X-radiation is not only emitted from the surface atoms of the target, but also from the atoms beneath the surface when they are impacted by the electrons of the cathode stream.[2]

(*e*) The electrons penetrate a short distance into the surface of the target, but their velocity diminishes rapidly with depth of penetration.

(*f*) The emitted X-rays are absorbed on their passage through matter. This absorption depends on the thickness and nature of the material traversed.

The only hypotheses adopted will be directly in keeping with the Bohr theory of the atom. The Bohr picture of the atomic mechanism, which is so successful in the case of the ordinary radiation from hydrogen,

[1] PHYS. REV., June, 1916.

[2] Kaye, X-rays, p. 40.

is almost equally successful in the case of characteristic X-radiation, since the frequencies of the K_α radiation from many elements may be readily calculated by the Bohr equation for the hydrogen atom.

According to this theory the frequency of the radiation emitted by an atom depends on the change of the potential energy of one or more electrons of the atom with respect to a central nuclear charge. This change of potential energy is *radial* with respect to the central nucleus.

It will be considered that radiation can only be excited by the transfer of energy from the *impacting* electron along a radius with respect to the center of the atom.

The mechanism of the atomic nucleus will be considered to emit a quantum of energy *whenever an impacting electron possesses such velocity that the energy due to the radial component of this velocity shall be equal to or exceed the minimum energy* (V_0e) *required for the excitation of the particular radiation.* The work done along the radius must be equal to or exceed the quantity (V_0e) where V_0 is the least voltage that will excite the characteristic radiation.

Let N represent the number of electrons striking the surface of the target per second. Let B represent the probability of any one electron making impact with or coming within the spheres of influence of the atomic nuclei in unit distance. The number of such impacts in a distance dx will be

$$BNdx.$$

The X-radiation appears to have its origin in the nucleus of the atom. It is considered that the impacting electron in order to excite the radiating mechanism of this nucleus must come within an undefined region about the nucleus which will be referred to as the sphere of influence of the nucleus. The probability Bdx of an electron striking one of these nuclear spheres in a path dx is quite small.

Not all of these $BNdx$ impacts with the nuclei will excite radiation, but a fraction of them will do so. The capacity to excite radiation depends on the nature of the impact. *Only those impacts will be effective in which the energy due to the radial component of the velocity is equal to or exceeds a minimum* (V_0e). This assumption which has previously been applied to ionization by impact[1] is, as has just been pointed out, in agreement with the Bohr theory of the atom.

The fraction of the BN electrons that are effective may be readily found by consideration of Fig. 1.

For the purpose of presenting a picture to the mind one may tentatively regard an atomic nucleus to be represented at C, and the bounding sphere

[1] PHYS. REV., Jan., 1907. An. d. Physik., Band 42, 1913.

of influence within which the electrons must penetrate in order to excite radiation to be represented by *abed*.

If the velocity of the electrons on approaching this bounding sphere is that corresponding to V_0, only those that make impact along the line *h* will be capable of producing the radiation. All other electrons will have a radial component too small to be effective. As the voltage is increased, electrons approaching the nucleus further from the atomic pole *a*, as along *fg*, may have a radial component at least equal to V_0. As the voltage is further increased electrons approaching along a line as far from the pole as *m n* may be effective. The fraction of the impacts that will be effective is the ratio of the cross-section of the zonal area *nn* to the area of cross-section of the nuclear sphere *bd*. This ratio may be expressed in terms of the voltage *V* and is

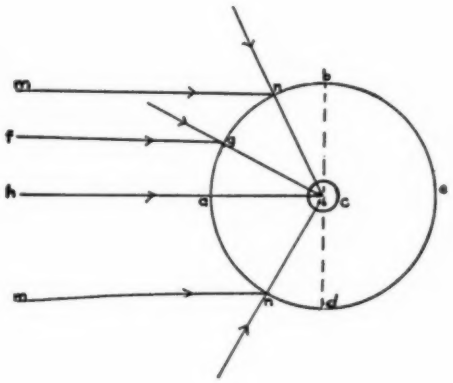


Fig1.

$$\frac{V - V_0}{V}.$$

Of $BNdx$ impacts in a region dx at a depth x within the target the fraction

$$\frac{V_x - V_0}{V_x}$$

will be effective in producing radiation where V_x is the voltage corresponding to the velocity that an electron may have at a depth x beneath the surface of the target.

Each of these effective impacts will emit a quantum of energy of some frequency. All of the X-radiation does not appear at one frequency, but there are other frequencies emitted in addition to the stronger α and β radiations. The electrons in general do not possess sufficient energy to excite both the α and β lines, since the energy required would be $(hn_\alpha + hn_\beta)$.

Of all the effective impacts, a fraction will produce a disturbance that results in the emission of radiation of one frequency, the K_α radiation for example. The fractional part of the total effective impacts that result in the production of radiation of frequency n_α will be designated

by E_a. This constant E_a will be more fully discussed in the last paragraph of this section of the paper. Each of these

$$E_a BN \frac{V_x - V_0}{V_x} dx$$

impacts will produce a quantum of energy hn_a. The energy radiated will be

$$dI_0 = E_a(hn_a)BN \frac{V_x - V_0}{V_x} dx. \tag{1}$$

The law of decrease of the velocity of electrons penetrating a metallic surface has been derived by Sir J. J. Thomson[1] and experimentally confirmed by Whiddington.[2] This law is expressed by the equation

$$v_x^4 = v^4 - ax, \tag{2}$$

where v_x is the velocity at a depth x and a is a constant depending on the nature of the material. This equation may be expressed in terms of the corresponding kilo-volts V and becomes

$$V_x^2 = V^2 - bx, \tag{3}$$

where b is the corresponding value of the constant a.

Equation (1) may then be written

$$I_0 = E_a(hn_a)BN\left[\int dx - \int \frac{V_0 dx}{(V^2 - bx)^{1/2}}\right]. \tag{4}$$

The X-rays when emitted from a region dx at a depth x below the surface will be subject to absorption in passing up through the material of the target. The quantity emitted from any depth x will be

$$I = I_0 e^{-\mu cx},$$

where μ is the coefficient of absorption of the material for the radiation of the given frequency, and cx is the thickness traversed by the rays in emerging from the target. The radiation actually emitted becomes:

$$I = E_a(hn_a)BN\left[\int_0^R e^{-\mu cx} dx - V_0 \int_0^R (V^2 - bx)^{-1/2} e^{-\mu cx} dx\right]. \tag{5}$$

The limit R is the range of the electrons before their velocity is reduced to that corresponding to the voltage V_0. From equation (3)

$$V_0^2 = V^2 - bR,$$

and

$$R = \frac{V^2 - V_0^2}{b}. \tag{6}$$

[1] Conduction Through Gases, p. 378.

[2] Proc. Roy. Soc., Vol. 86, 1912.

The indefinite integral of (5) is not obtainable, but a close approximation may be obtained by expanding the exponential term. Since this expanded term is rapidly convergent for the values μcx here required it is necessary to retain only a few terms of the series. The resulting integral is

$$I = E_a(hn_a)\frac{BN}{b}\left[\frac{b}{c\mu}(1 - e^{-(c\mu/b)(V^2-V_0^2)})\right.$$
$$- 2V_0(V - V_0) + \frac{2}{3}\frac{c\mu}{b}V_0\{2V^3 - V_0(V^2 + V_0^2)\}$$
$$\left. - \frac{V_0}{15}\left(\frac{c\mu}{b}\right)^2\{8V^4(V - V_0) - 4V^2V_0(V^2 - V_0^2)\right.$$
$$\left. - 3V_0(V^2 - V_0^2)^2\}\right]. \quad (7)$$

The variable part of this equation contains no arbitrary constants. The constants b and $c\mu$ may be obtained by independent experiment.

In order to compare this equation with experiment, I have taken some results just obtained by Mr. B. A. Wooten (not yet published) for the emission of the K characteristic (α line) radiation from molybdenum. The difficulty of making this comparison arises from the fact that no experimental results are at hand either for the decrease of velocity of electrons (constant b) or for the absorption of rays of this particular frequency (constant μ) for molybdenum.

The constant a has been determined by Whiddington[1] for gold and aluminium.

(Al.) $$a = 7.32 \times 10^{42}.$$

(Au.) $$a = 2.54 \times 10^{43}.$$

If the density of the material be represented by ρ

(Al.) $$\frac{a}{\rho} = 2.83 \times 10^{42}.$$

(Au.) $$\frac{a}{\rho} = 1.33 \times 10^{42}.$$

The stopping power of a metal does not appear to be directly related to its density. One can only estimate its value for molybdenum. In the absence of experimental data I shall tentatively assume a value between that found for gold and aluminium.

Taking $a/\rho = 2.2 \times 10^{42}$, the value of a is 1.9×10^{43}. The corresponding value of this constant when the velocity is expressed in terms of kilovolts is

$$b = 1.5 \times 10^6.$$

[1] Loc. cit.

The absorption coefficient μ of molybdenum for its own K characteristic radiation has not been determined, but the coefficient of absorption of these rays in silver is given by Kaye[1] as

$$\frac{\mu}{\rho} = 24.4.$$

Since molybdenum does not differ much from silver in atomic weight and density, this will be provisionally taken as the absorption coefficient of molybdenum for its own characteristic radiation.

$$\mu = 200.$$

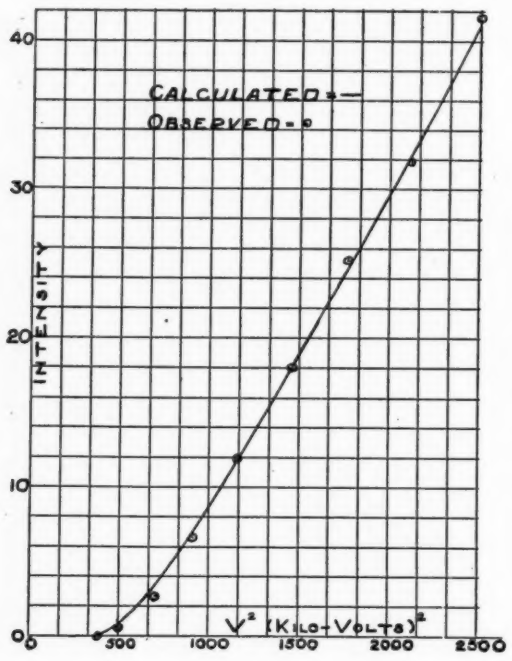


Fig. 2.

In the particular experiments of Wooten the X-rays were taken from the target at such an angle that the path of the rays emerging from the target was about 1.5 times the path (x) of the penetrating electrons that produced them. The constant c is 1.5. The group constant $b/c\mu$ of equation (7) has the approximate numerical value 5,000.

The theoretical equation as derived is calculated and plotted in Fig. 2. The curves are plotted with the square of the applied voltage (kilovolts) as abscissæ, since this makes the greater part of the curve nearly a straight line. The circled points represent the observed results obtained by Wooten.

The form of the calculated curve is similar to that obtained by experiment. Since the variable part of the equation contains no arbitrary constants, the assumptions underlying its derivation appear to be justified.

The energy of emission of different elements may be expected to increase rapidly with the atomic number. The energy emitted is proportional to hn, where n is a frequency slightly greater than that of the $K\beta$ characteristic of the element, and this frequency is nearly proportional

[1] X-rays, Kaye, p. 138.

to the square of the atomic number. If the constant E_α were of the same value for all elements, this increase in emissivity would be approximately proportional to the quantum hn.

The factor B, which is a constant for any one element, may depend on the atomic number. The introduction of this constant is required, since it is assumed that every *effective* electron at impact will give rise to a quantum of radiant energy. The fraction of the total electrons of the cathode stream that are effective must be very small. The greater part of them dissipate their energy directly in the production of heat, or indirectly by the excitation of other types of radiation by disturbance of the electrons in the outer regions of the atom. It is possible that the greater part of the transfer of kinetic energy of the impacting electrons to the atoms does not take place directly through the interchange of momentum, but they may excite radiation in the ultra-violet, visible and infra-red regions by disturbance of the more loosely bound electrons of the atom. This radiation is absorbed by the atoms and finally appears as heat.

Equation (7) without the constant $E_\alpha(hn_\alpha)$ would represent the number of impacts of the electrons that have a radial component of velocity *equal to or greater* than that corresponding to the critical voltage V_0. All the energy of these effective impacts cannot appear as radiation of any one frequency, n_c for example (where n_c is the frequency corresponding to the critical voltage V_0). There are at least two strong lines (α and β) and a number of weaker lines in the K-radiation, also there are a number of lines in the L characteristic radiation. In addition there is the general radiation of the "continuous" X-ray spectrum. Each effective electron at impact gives rise to only one quantum of energy, so that the same electron cannot excite the characteristic lines as well as the general radiation. There must be some statistical partition between the number that give rise to each type of radiation.

The constant E_α expresses the fraction of the effective impacts that excite radiation of one frequency and the combined constant E_α (hn_α) expresses the fraction of the radiated energy produced by the effective BN electrons that appear as radiation of one frequency, the K_α radiation in the present discussion.

This partition or distribution of energy between the characteristic and the general radiation appears to be nearly constant and independent of the voltage. The experiments of Brainin[1] show that the total radiation (characteristic plus general) from molybdenum increases as the square of the applied voltage. The experiments of Wooten show that

[1] PHYS. REV., Nov., 1917.

the characteristic radiation increases approximately according to the same law. It follows that the partition of energy between the two types is constant independent of the voltage.

X-RADIATION FROM THIN FILMS.

D. L. Webster[1] has proposed experiments with thin films for the purpose of studying the nature of the general or "white" X-radiation. An investigation of the emission of characteristic (line) radiation from thin films would also be of interest and value.

The rapid increase of the emitted energy with increase of voltage may be regarded as due to two causes:

(*a*) The increase in the emission from each atomic nucleus due to the increased energy of the impacting electrons.

(*b*) The penetration of the electrons into deeper layers of the target with sufficient energy to excite the radiation.

In the case of thin films, if the velocity of the electrons at entrance to the film is sufficiently great they may pass completely through the film and emerge on the far side with sufficient energy still to produce radiation. The part of the radiation that would have been produced by these electrons after passing through the film will be absent and the curve representing the emitted energy will have a break at this point.

A convenient method of investigating this by experiment would be to deposit a thin film of the metal of known thickness upon another metal as a support. If the frequency of the characteristic radiation of the solid supporting target differs from that of the film, the line radiation of the supporting element will not enter the slit of the spectrometer. The radiation from films much thinner than could be independently supported may thus be readily investigated.

From such a film as the voltage is increased the radiated energy will at first increase rapidly in intensity. When the voltage becomes such that the electrons emerge from the far side with an energy greater than (V_0e), the increase in radiation will not be so rapid. That part of the emission due to deeper penetration at this voltage will be absent. There will be a change in the slope of the radiation curve as indicated at *b*, Fig. 3. This will be true independently of any special theory of X-ray emission other than that a portion of the increased emission is due to deeper penetration of the electrons into the target. This phenomenon furnishes a convenient method for measuring the decrease of velocity of electrons on passing through matter. Thus the point *b* in Fig. 3 corresponds to a voltage across the X-ray tube of about 33.5 kilovolts. The

[1] PHYS. REV., March, 1917.

electrons entered the film with a velocity corresponding to 33.5 kilovolts, and emerged from the far side with a velocity corresponding to $V_0 = 19.2$ kilovolts. These results are calculated for a film of molybdenum 5×10^{-4} cm. thick using the value of the constant b previously deduced from Whiddington's experiments.

The form of the radiation curve for a thin film may be readily derived in a similar manner to that for a solid target.

Consider a film of thickness d deposited on a solid support. The radiation will be that from a solid target of the same material as the film *less* that emitted by the portion of the solid target lying at a depth greater than d.

$$I_f = E_a(hn_a)BN\left[\int_0^R \frac{V_x - V_0}{V_x} e^{-\mu cx} dx - e^{-\mu cd} \int_0^R \frac{V_{x_1} - V_0}{V_{x_1}} e^{\mu cx_1} dx_1\right].$$

The depth of the electron within the surface of the solid portion of the target is designated by x_1. All of the radiation produced in the x_1 region passes through the film of constant thickness d, hence the absorption due to the film d may be placed outside the integral sign.

The first term of the right-hand member is the same as equation (5). Let I represent this term. Let I_s represent the second term.

$$I_f = I - I_s, \tag{8}$$

$$I_s = E_a(hn_a)BN \int_0^R \frac{V_{x_1} - V_0}{V_{x_1}} e^{-\mu cx_1} dx_1. \tag{9}$$

Introducing the law of decrease of electron velocity

$$V_{x_1}^2 = V_d^2 - bx,$$

and expanding the exponential, the equation is integrated as in the case of (7).

The voltage corresponding to the velocity with which the electrons emerge from under side of film and enters the X_1 region is designated by V_d. The range R of the electrons in the X_1 region is

$$V_0^2 = V_d^2 - bR.$$

The R limit is

$$R = \frac{V_d^2 - V_0^2}{b}.$$

The integral of (9) for the specified limit is

$$I_s = E_a(hn_a)\frac{BN}{b} e^{-\mu cd}\left[\frac{b}{c\mu}(1 - e^{-(c\mu/b)(V_d^2 - V_0^2)})\right.$$

$$\left. - 2V_0(V_d - V_0) + 2/3\frac{c\mu}{b} V_0\{2V_d^3 - V_0(V_d^2 + V_0^2)\}\right]$$

$$-\frac{V_0}{15}\left(\frac{c\mu}{b}\right)^2\{8V_d^4(V_d - V_0) - 4V_d^2V_0(V_d^2 - V_0^2) - 3V_0(V_d^2 - V_0^2)^2\}\Big]. \quad (10)$$

The value of V_d is given by the relation

$$V_d^2 = V^2 - bd,$$

where V is the voltage applied to the X-ray tube.

The above equation is zero for $V_d = V_0$ as it should be. It is to be calculated only for values of V_d greater than V_0. A plot of this equation is shown at $n\ m\ p$ in Fig. 3. The constants b and μ are given the same

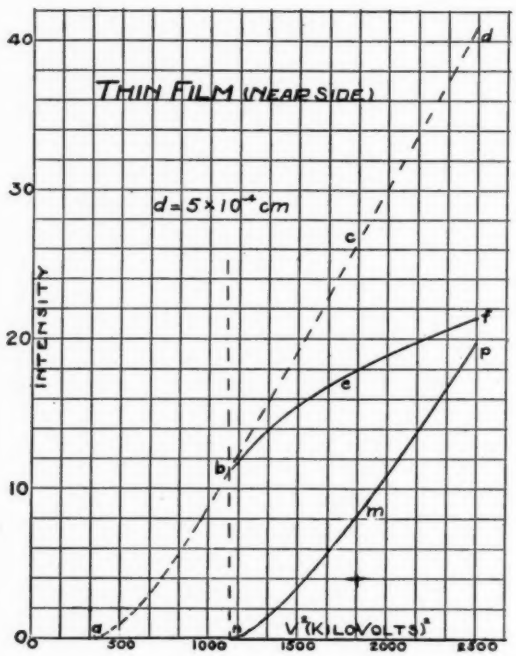


Fig. 3.

values as in the plot of Fig. 2. The thickness of the film is taken to be $d = 5 \times 10^{-4}$ cm.

This curve is subtracted from the curve $a\ b\ c\ d$ as indicated by (8). The resultant curve $a\ b\ e\ f$ represents the radiation from a thin film.

The equation and its plot indicate that the radiation could not indefinitely increase, but at a high voltage it would approach a maximum independent of the voltage. Consideration of the physical processes involved would also lead one to anticipate this result.

An inspection of equation (7) for large values of μ (that is very soft

rays) shows that the radiation from a solid target (Fig. 2) would not indefinitely increase with the voltage. The energy emitted will tend toward a maximum independent of the voltage. This result is also to be expected from a consideration of the physical processes involved. In the case of elements such as copper, chromium, etc., which have a characteristic radiation of long wave-lengths, the radiation emitted from atoms at considerable depths below the surface would be largely absorbed in the target. The resultant emission would be similar to that from thin films. The above remarks are true in a degree for the characteristic emission from all elements. The energy radiated cannot increase indefinitely with the voltage. This is necessarily true, otherwise at extremely high voltages the radiated energy might become greater than that of the bombarding electron stream—a result that is manifestly impossible.

EMISSION FROM THIN FILMS. (FAR SIDE.)

Another matter of interest is the emission of the characteristic radiation from the far side of a thin film. The expression for the radiation for this case is readily derived by the methods pursued in the previous developments.

Let the thickness of the film be designated by d. The thickness of material traversed by the X-rays emitted from any depth x and emerging from the far side will be $(d - x)$.

The radiation may be represented by

$$I = E_a(hn_a)BN \int_0^R \frac{V_x - V_0}{V_x} e^{-\mu(d-x)} dx. \tag{11}$$

Since

$$V_x^2 = V^2 - bx,$$

$$I = E_a(hn_a)BNe^{-\mu d}\left[\int_0^R e^{\mu x} dx - V_0 \int_0^R \frac{e^{\mu x} dx}{(V^2 - bx)^{1/2}}\right]. \tag{12}$$

The constants and the limit R have the same significance as in the equation for a solid target.

The integral equation is

$$I = E_a(hn_a)BN \frac{e^{-\mu d}}{b}\left[\frac{b}{\mu}(e^{-(\mu/b)(V^2 - V_0^2)} - 1)\right.$$

$$- 2V_0(V - V_0) - \frac{2}{3}\frac{\mu}{b} V_0\{2V^3 - V_0(V^2 + V_0^2)\}$$

$$\left. - \frac{1}{15}\left(\frac{\mu}{b}\right)^2 V_0\{8V^4(V - V_0) - 4V^2V_0(V^2 - V_0^2) - 3V_0(V^2 - V_0^2)^2\}\right].$$

A plot of this equation is shown in Fig. 4. It is to be noticed that the curve is much more concave upward than the curve for the emission from a solid target (Fig. 2). The variable part of the equation does not con-

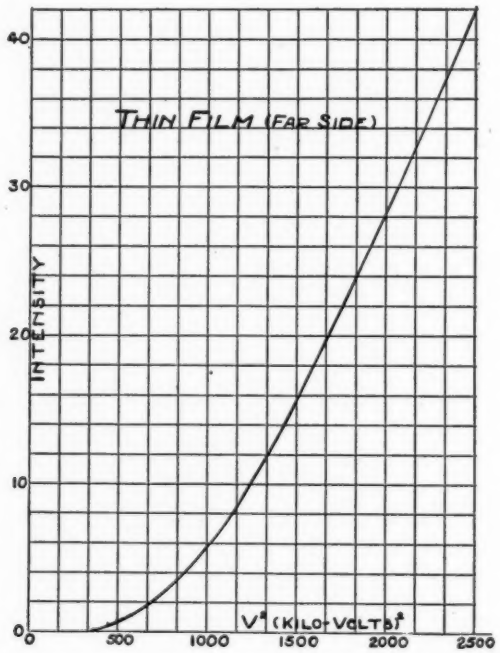


Fig. 4.

tain the term involving the thickness of the film. The form of the radiation curve is independent of the thickness of the film provided this thickness is greater than the range R of the electrons producing the radiations.

PHŒNIX PHYSICAL LABORATORY,
COLUMBIA UNIVERSITY,
January, 1918.

ON THE FORMATION OF NEGATIVELY ELECTRIFIED RAIN DROPS.

By Fernando Sanford.

IT is known that in fair weather the electrical condition of the atmosphere is usually positive everywhere over the earth's surface. This is regarded as the normal condition of the atmosphere, and it is subject to periodical changes which for a given place are fairly constant, day after day and year after year. It is also well known that on account of its high specific inductive capacity water will take a positive electrical charge by contact with nearly all known substances. Lord Kelvin, Lenard and especially Coehn and Mozer[1] have shown that gases bubbled through pure water carry off charges and leave the water positively electrified. This makes it practically certain that the positive electrification of the air is located upon the minute drops or the molecules of water in the air.

It has also been known for a long time that the air in the vicinity of waterfalls becomes negatively electrified, and Elster and Geitel showed that this condition may be appreciable to heights of at least 500 meters above the waterfall. Lenard[2] showed that the negative electrification arises near the foot of the waterfall where the water is dashed or blown into spray, and that it seems to occur wherever in rapids or falls spray is produced, while it is imperceptible over a smoothly flowing stream.

Dr. Simpson[3] showed that when drops of distilled water fall through a vertical air blast strong enough to produce spray the small drops of water formed have negative charges much more often than positive charges. Since the small drops are carried upward much faster by a rising current and since they fall more slowly through still air than the large drops, they may become separated by air currents or by gravitation from the larger electropositive drops. Since drops of water cannot fall through still air faster than about 8 meters per second without being torn to pieces by atmospheric resistance, it would seem that an electric separation must be produced whenever large raindrops fall from a considerable elevation.

[1] Ann. d. Phys., *43*, 1048 (1914).

[2] Ann. d. Phys., *46*, 584 (1892).

[3] Quoted from Humphreys's article on "The Thunderstorm and Its Phenomena" in Monthly Weather Review, June, 1914.

Given the small negatively electrified drops that are thus blown off from the positive drops, it seems possible to account for all the phenomena of thunderstorms, and Humphreys has done this very successfully in the paper to which reference has been made. The question which seems thus far to have been impossible of explanation is how negatively electrified drops may be blown from positively electrified drops by a wind which regularly gives off positive charges to water. In order to find an answer to this question it is important to know how exretmely small drops, such as take negative charges, may be formed from larger drops.

It has frequently been observed that when a drop of liquid breaks away from a larger mass the liquid which joins the drop to the larger mass is drawn out into a narrow cylindrical neck before it is pinched off at one end by the contraction of its surface film. Plateau[1] has shown that a liquid cylinder is in a condition of unstable equilibrium when its length exceeds about three (π) times its diameter. Such a cylinder will break up into segments whose distances apart are approximately equal to the circumference of the cylinder, and these segments spontaneously take the spherical form. Accordingly, when such a liquid cylinder has been drawn out between two separating drops and is pinched off at one end by its surface film it immediately forms one or more small drops which break away from the larger drop.

The formation of these little drops between larger ones has frequently been shown photographically, but it may be observed directly without any artificial aids. Thus if ink be dropped from a pen filler which is held before an illuminated white surface, as a sheet of white paper against a windowpane, a small drop may almost invariably be seen following the larger drop. If a low power magnifying glass be placed in front of the falling drop so that it will come into the field of view just after breaking away from the dropper, the little drop may be seen to form from the liquid neck which clings to the falling drop instead of to the dropper. That is, the liquid which forms the little drop breaks away from the dropper and then later from the falling drop. The little drops may be collected and their size compared with that of the larger drop by catching them on a moving piece of paper. Since the little drop falls more slowly than the large drop it may easily be caught to one side of it. The same thing may be done by giving the dropper a horizontal motion just as the drop separates from it. When the drops are collected in this way, the large drop is seen to have several thousand times the volume of the little droplet.

If a drop of ink or of colored glycerine be dropped through a hori-

[1] Statique Des Liquides, Vol. 1, p. 75.

zontal air blast, such as is used with a laboratory blow pipe, the drop will be blown to pieces if the velocity of the air is sufficiently high. By spreading sheets of paper below the falling drop the separate drops may be collected. It will then be seen that there are a few larger drops and a great many little droplets. If the blast is not too strong, the original drop still remains larger than any of the others, and the drops of intermediate size are apparently blown off from this one at a time. This conclusion may be verified by dropping a liquid from a sufficient height to cause the drops to be separated by air friction, when it will be seen that the first division is into two drops of very unequal size. Figure 1 shows a photograph of the splashes made on a sheet of absorbent paper by a drop of ink falling from a height of about 20 feet. An observer noticed that the drop struck the paper as two separate drops, and the splashes show that one was much larger than the other.

Fig. 1.

It is plain that when the drops of intermediate size are blown off from the larger drop there are always one or more of the little droplets formed from the liquid neck which is drawn out between the two, and these tiny droplets are those which receive the negative charges. The conditions for forming the negative droplets are then pretty definitely known. First, a drop smaller than the original positively electrified drop is blown off from it. This drop is also positively electrified. Before it breaks away from the original drop, a narrow neck of water is drawn out between them. This breaks away from the original drop, then from the secondary drop, and becomes a negatively electrified droplet.

This phenomenon of charging a small body by induction between two similarly electrified bodies may easily be reproduced in the laboratory. If two insulated metal spheres or cylinders of unequal radius be placed in contact and charged positively and then be separated to a small distance while still remaining charged, a very small insulated sphere when introduced between them may take a positive charge by contact with the surface of the larger sphere or cylinder or a negative charge by contact with the smaller. Thus the inductive effect of the larger sphere upon the smaller is sufficiently great to cause it to give off a negative charge to a small conductor touched to the point nearest to the larger sphere; or to put it another way, the charge which the little conductor may take by induction between the two spheres is greater than the opposite charge which it may take from the smaller sphere while in the same position.

The conditions under which the negatively electrified water droplets are formed seem to be exactly reproduced in this laboratory experiment. The little droplets are formed between two positively electrified drops of unequal size. They break away first from the larger drop, and then while still very close to it, from the smaller drop, taking a negative charge by induction of the larger drop.

The only reference to the above induction experiment which the present writer has been able to find in the literature of electricity is in Dr. Thomas Thomson's Heat and Electricity, which was published in 1830. Dr. Thomson attributes the discovery of the phenomenon to Coulomb. He says that by using two globes, one 11 inches in diameter and the other 8 inches in diameter, which were positively charged while in contact, Coulomb was able to take a negative charge from the smaller globe when their surfaces were separated by one inch, and that when a globe 4 inches in diameter was used with the 11-inch globe, Coulomb was able to take a negative charge from the smaller globe when they were two inches apart.

STANFORD UNIVERSITY,
January 22, 1918.

THE AIR-DAMPED VIBRATING SYSTEM:[1] THEORETICAL CALIBRATION OF THE CONDENSER TRANSMITTER.

BY I. B. CRANDALL.

IN a recent paper[2] Mr. E. C. Wente has given an account of the condenser transmitter which he developed for the purpose of measuring sound intensities in absolute terms. This instrument has a sensibility which is nearly uniform over a wide range of frequencies—a property which results from the high stiffness and dissipation brought into play by the air film between plate and diaphragm.

In further work with the condenser transmitter, I have made a study of the air-damping and elasticity as they occur in this instrument and a treatment of these matters may be of interest as an extension of the mechanics of the system. To anticipate the results, it has been found that both damping and stiffness can be calculated according to a simple theory, and that there are important frequency variations in these quantities. For example, Wente found that the damping coefficient of his system at resonance was of the order of 6,000, while theory and experiment show that the damping at 100 p.p.s. is more than 100 times as great. The theory enables an absolute calibration curve to be readily computed which is sufficiently accurate for practical purposes,[3] and in addition shows how various combinations of resistance and stiffness can be given to a vibrating system, by a suitable application of the air-damping film.

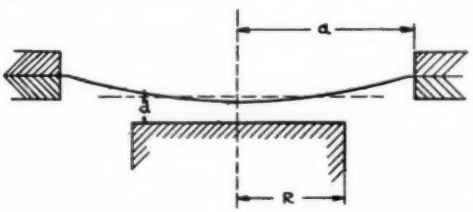


Fig. 1.

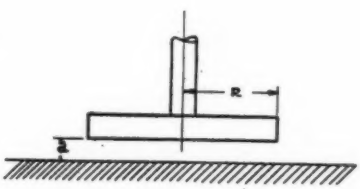


Fig. 2.

The condenser transmitter is shown diagrammatically in Fig. 1. When the diaphragm vibrates it causes two kinds of motion in the air film:

[1] Paper presented at meeting of the American Physical Society, December 28, 1917.

[2] PHYS. REV., N. S., Vol. X., 1917, p. 39.

[3] This paper deals with the calibration at various frequencies in terms of the calibration at zero frequency. The calibration at zero frequency has been given by Wente.

simple compression, and a lateral escape of air towards the edge of the disc. At very low frequencies the air has ample time to escape, consequently there is a maximum amount of dissipative reaction (due to viscous flow) and a minimum of elasticity due to accumulated pressure in the film. At high frequencies the situation is reversed, and very little air escapes from the edge of the disc, thus giving rise almost wholly to a compressive reaction.

For the sake of simplicity we shall first consider a system in which the diaphragm is replaced by a plane piston of equivalent mass, the radius of the piston being equal to the radius of the disc (Fig. 2). The piston is given an oscillating motion $\xi = \xi_0 \cos nt$. As the air film is thin, and both bounding surfaces are of metal, the expansion and contraction of the air take place isothermally, and the excess pressure at any point in the film due to simple compression is $B(\xi/d)$ in which B is the atmospheric pressure.[1]

From this must be subtracted the decrease in pressure due to lateral air flow which takes place symmetrically toward or from the center of the disc; this is

$$p' = p - B\frac{\xi}{d} = -B\left(\frac{d\eta}{dr} + \frac{\eta}{r}\right), \tag{1}$$

in which p is the total excess pressure and η the radial air displacement. There is no pressure gradient normal to the radius. The radial pressure gradient is

$$\frac{dp}{dr} = \frac{dp'}{dr} = -B\left(\frac{d^2\eta}{dr^2} + \frac{1}{r}\frac{d\eta}{dr} - \frac{\eta}{r^2}\right). \tag{2}$$

In the theory of fluid motion in narrow crevices it is shown that the velocity of motion[2] is proportional to the pressure gradient:

[1] The following considerations justify the use of the isothermal hypothesis. The velocity of propagation of heat waves in a gas is $\sqrt{4\pi fk}$ in which f is the frequency and k the "diffusivity" of the gas (.17 cm²/sec at 0° for air). Assuming that compression at first raises the temperature of the interior of the film, a large part of the film should cool to the same temperature as the metallic boundary within a time comparable to that taken by a temperature wave, originating in the center of the film, to reach the boundary. For example, in a film whose half thickness is 1.1×10^{-3} cm. this propagation time at 20,000 frequency is approximately 5×10^{-6} sec. or about one tenth of the period of vibration. Thus even in extreme cases the temperature adjustment in the film is practically instantaneous.

As there is little compression at low frequencies, it is to be expected that the low-frequency resistance formula (equation 11*a*) would be independent of any assumption as to the nature of the compression. Consequently from low-frequency measurements on resistance no evidence could be obtained as to which hypothesis is the proper one to use. At higher frequencies, however, where compression is an important factor, the evidence is in favor of the isothermal hypothesis: the good agreement between the calculated and observed values of the damping of Wente's system at 17,000 cycles being upset if the adiabatic hypothesis is used.

[2] This theory frankly neglects the inertia of the moving air; the results of experiment justify this in the case considered.

$$u = \frac{d\eta}{dt} = -\frac{1}{\kappa}\frac{dp}{dr}, \tag{3}$$

in which κ is a resistance coefficient appropriate to the shape of the crevice. For a fluid of viscosity μ flowing between parallel walls separated by a distance d,

$$\kappa = \frac{12\mu}{d^2}.^1 \tag{4}$$

From (1) and (3) we have the equation for the excess pressure

$$\frac{d^2p'}{dr^2} + \frac{1}{r}\frac{dp'}{dr} = \frac{\kappa}{B}\frac{dp'}{dt}, \tag{5}$$

the solution of which is, for the state of steadily maintained vibrations,

$$p' = [CI_0(\alpha r\sqrt{i}) + DK_0(\alpha r\sqrt{i})\epsilon^{int}], \tag{6}$$

in which I_0 and K_0 are the Bessel's functions of zero order of the complex variable having an argument $-\pi/4$,

$$\alpha = \sqrt{\frac{n\kappa}{B}}$$

and C, D, are adjusted to the boundary conditions.

On account of symmetry about the center of the disc the velocity $u = 0$ when $r = 0$, which specifies that the pressure gradient shall vanish when $r = 0$, thus disposing of the term in $K_0(\alpha r\sqrt{i})$. Writing for C, $C'\epsilon^{i\Phi}$ and using $I_0(\alpha r\sqrt{i}) = \text{ber}\,\alpha r + i\,\text{bei}\,\alpha r$, we have, retaining only the real terms,

$$p' = p - B\frac{\xi}{d} = C'[\text{ber}\,\alpha r\cos(nt + \Phi) - \text{bei}\,\alpha r\sin(nt + \Phi)]. \tag{7}$$

To determine C' and Φ we note that the pressure p vanishes at the edge of the disc because of the free communication with the atmosphere.[2] Evaluating these constants we have finally

$$p = \frac{B\xi_0}{d}\left(1 - \frac{\text{ber}\,\alpha r\,\text{ber}\,\alpha R + \text{bei}\,\alpha r\,\text{bei}\,\alpha R}{\text{ber}^2\,\alpha R + \text{bei}^2\,\alpha R}\right)\cos nt$$
$$- \frac{B\xi_0}{d}\left(\frac{\text{ber}\,\alpha r\,\text{bei}\,\alpha R - \text{bei}\,\alpha r\,\text{ber}\,\alpha R}{\text{ber}^2\,\alpha R + \text{bei}^2\,\alpha R}\right)\sin nt. \tag{8}$$

The coefficient of $\cos nt$, being in phase with the amplitude ($\xi_0\cos nt$) of the piston represents pure compression, while the coefficient of $\sin nt$ is in phase with the velocity ($-\xi_0 n\sin nt$) and represents pressure

[1] Lamb, Hydrodynamics, 4th ed. (1916), p. 576.

[2] The volume of air in the channel around the disc in Wente's instrument was about 100 times that of the air in the film between plate and diaphragm.

dissipated in producing air flow. These two coefficients must be integrated over the area of the piston in order to obtain the elastic constant (S) and the resistance constant (ρ) of the system. That is

$$s\frac{d\xi}{dt} = -\rho\xi_0 n \sin nt = 2\pi\int_0^R p_{\sin}\cdot r\cdot dr \tag{9}$$

and

$$s\xi = s\xi_0 \cos nt = 2\pi\int_0^R p_{\cos} r\, dr, \tag{10}$$

whence

$$\rho = \frac{2\pi BR}{nd\alpha}\left(\frac{\text{bei}\,\alpha R\,\text{bei}'\,\alpha R + \text{ber}\,\alpha R\,\text{ber}'\,\alpha R}{\text{ber}^2\,\alpha R + \text{bei}^2\,\alpha R}\right) \tag{11}$$

and

$$s = \frac{\pi BR^2}{d}\left(1 - \frac{2}{\alpha R}\,\frac{\text{ber}\,\alpha R\,\text{bei}'\,\alpha R - \text{ber}'\,\alpha R\,\text{bei}\,\alpha R}{\text{ber}^2\,\alpha R + \text{bei}^2\,\alpha R}\right). \tag{12}$$

To s must be added whatever stiffness the system possesses independently of the air film; *i. e.*, the inherent stiffness in the diaphragm.

The Air-Damped System at Low Frequencies.

For frequencies near zero, s vanishes and we have to consider only the resistance constant, which may rise to enormous values if the air film is thin. For values of $\alpha R < 1.00$ (11) becomes[1]

$$\rho = \frac{2\pi B\alpha^2 R^4}{16nd} = \frac{3}{2}\,\frac{\pi\mu R^4}{d^3}, \tag{11a}$$

using the value of κ from (4).

Formula (11*a*) has been subjected to experimental test by Mr. F. W. Kranz, of this laboratory, using a very heavy vibrating system, and measuring the damping for three values of air gap. The condenser transmitter was arranged as in Fig. 3, a heavy disc M being fastened to

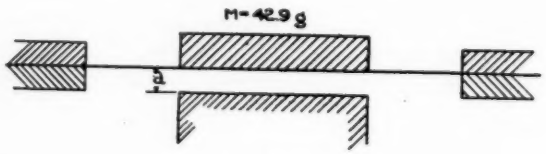


Fig. 3.

the diaphragm to insure piston-motion at the center, and also to bring the natural frequency of the system down to a few hundred cycles. The transmitter was polarized in the usual way and connected through a

[1] See Russell, Phil. Mag., April, 1909, p. 524 on "Methods of Computing ber and bei Functions, etc."

distortionless two-stage amplifier to an oscillograph. Impulses were given to the system by tapping M lightly with a pencil, and oscillograms of the natural oscillations taken from which the damping was easily determined. The data are given in the following table:

Total moving mass $M = 42.9$ g. (including diaphragm).
Radius of discs $R = 1.63$ cm.
Viscosity of Air, $\mu = 1.8 \times 10^{-4}$ gram/cm. sec.

Separation d.	Number of Determinations.	Mean Damping, Δ.	Resistance $\rho = 2M\Delta$.	Resistance $\rho = \frac{3\pi\mu R^4}{2d^3}$.	Frequency of Oscillations (Approx.).
0.0029 cm.	3	3,400	292,000	246,000	50[1]
0.0069 "	10	196	16,800	18,600	500
0.0124 "	2	34	2,900	3,100	500

Considering the difficulty of measuring the separation accurately, and the fact that the resistance is very sensitive to changes in separation, the theory can be taken as practically verified at low frequencies.

Still dealing with the low frequency case, it is worth while inquiring how great will be the departure from (11a) when the moving piston is replaced by a flexible membrane, as in the condenser transmitter. Assuming that the membrane takes the shape of a paraboloid when distended, and that pressure reactions from the film do not change this shape appreciably, let us consider the simplest case, in which membrane and disc have the same radius, R.

The form of the membrane at any instant is given by

$$\xi(r) = \xi_0\left(1 - \frac{r^2}{R^2}\right)\cos nt, \tag{13}$$

the static and dynamic deflections being taken as small compared with the thickness of the air film. Instead of (2) the pressure must satisfy the equation:

$$\frac{d}{dt}\left[p - B\frac{\xi_0}{d}\left(1 - \frac{r^2}{R^2}\right)\epsilon^{int}\right] = \frac{B}{\kappa}\left(\frac{d^2p}{dr^2} + \frac{1}{r}\frac{dp}{dr}\right), \tag{2'}$$

the solution of which is

$$p = \frac{B\xi_0}{d}\left(1 - \frac{r^2}{R^2}\right)\epsilon^{int} + CI_0(\alpha r\sqrt{i})\epsilon^{i(nt+\Phi)} - \frac{4B^2\xi_0}{inR^2d\kappa}e^{int}. \tag{6'}$$

The I_0 function being chosen as before in order that the pressure gradient shall vanish when $r = 0$. Determining C and Φ for the pressure to vanish at the boundary, we have

[1] Nearly aperiodis.

$$p = B\xi_0\left[\left(1 - \frac{r^2}{R^2}\right) - \frac{4B^2}{\kappa n R^2}\frac{(\text{ber}\,\alpha r\,\text{bei}\,\alpha R - \text{bei}\,\alpha r\,\text{ber}\,\alpha R)}{\text{ber}^2\,\alpha R + \text{bei}^2\,\alpha R}\right]\cos nt$$

$$- \frac{4B^2\xi_0}{\kappa d n R^2}\left[1 - \frac{\text{ber}\,\alpha r\,\text{ber}\,\alpha R + \text{bei}\,\alpha r\,\text{bei}\,\alpha R}{\text{ber}^2\,\alpha R + \text{bei}^2\,\alpha R}\right]\sin nt. \qquad (8')$$

Now as αR is small, we may use approximations for the ber and bei functions and neglect all terms higher than $\alpha^4 R^4$.[1] Making the proper substitutions, we have

$$p = \frac{B\xi_0}{d}\frac{\alpha^4 R^4}{32}\left(1 - \frac{r^2}{R^2}\right)\cos nt - \frac{\kappa n \xi_0 R^2}{16d}\left(3 - \frac{r^2}{R^2}\right)\left(1 - \frac{r^2}{R^2}\right)\sin nt. \quad (14)$$

Considering only the resistance factor, the rate of dissipation of energy in the system is

$$\pi n \int^R \xi(r)\cdot p_{\sin}\cdot r dr = \frac{11}{32}\frac{\pi\mu R^4}{d^3}\cdot n^2\xi_0^2. \qquad (15)$$

In a condenser transmitter, a paraboloidal membrane with disc of equal size can be replaced (from the standpoint of electromotive force generated) by a plane piston of equal area, whose amplitude of motion is one half that of the membrane at its center. In terms of this average amplitude ξ' the rate of dissipation of energy is $\frac{1}{2}\rho' n^2 \xi'^2 = \frac{1}{8}\rho' n^2 \xi_0^2$. Equating this to (15) we have for the average resistance constant of the membrane system

$$\rho' = \frac{11}{4}\frac{\pi\mu R^4}{d^3}. \qquad (11'a)$$

The membrane transmitter thus experiences at low frequencies a resistance to motion nearly twice as great as the piston instrument which would generate the same electromotive force, both membrane and piston being damped with an air layer extending to the edge.

In Wente's instrument the radius of the disc was three quarters of the radius of the diaphragm. The average deflection of the diaphragm over the surface of the disc was 0.69 of the maximum. It is clear that the resistance constant of this device at low frequencies should have a value intermediate between that given by (11*a*) and that given by (11'*a*).

In practice, we may wish to damp a membrane with a disc of smaller size placed close to its center. In this case the piston formula is probably sufficiently exact.

In other cases, as for example using annular damping plates, or discs perforated with a number of holes, the damping can be calculated by an obvious extension of this theory. The formulæ for annular damping are somewhat complicated and need not be given here. The perforated

[1] Russell, loc. cit.

disc (with large holes and close adjustment to diaphragm) can be considered from the standpoint of damping as equivalent to a number of small discs of a certain size, and the determination of the diameter of the equivalent small discs is not a difficult matter.

As an immediate application of the "low-frequency" theory, consider the problem of applying a maximum of damping to a piston system of arbitrary area, without adding to the stiffness of the system. It is clear that the separation d of the damping disc should be small, while at the same time the quantity

$$\alpha R = \frac{R}{d}\sqrt{\frac{24\pi\mu f}{B}}$$

should be less than unity for the frequency at which the natural oscillations take place. The conclusion is that a number of separate damping "discs" should be used of such a size that the ratio R/d has the proper value: or, if a one-piece damping plate is applied, it must be furnished with suitably spaced holes or grooves to allow the escape of the imprisoned air.

The Air-Damped System at High Frequencies.

The painstaking and accurate calibration data given by Wente for the condenser transmitter from zero to 18,000 frequency offer the best possible check on the calculated values of the resistance and elasticity of this system over an extended range of frequencies. The following data were taken by Wente:

(1) Static calibration (zero frequency).
(2) Calibration at 20 p.p.s. using piston apparatus.
(3) Calibration from 20 to 120 p.p.s. using platinum thermophone in (large) air enclosure.
(4) Calibration from 160 to 18,000 p.p.s. using gold-leaf thermophone in a smaller volume of hydrogen.

In looking over these data we find that the calibration from 20 to 80 p.p.s. agreed with the static calibration to within 4 per cent. From 80 to 120 cycles, the calibration showed a 20 per cent. decrease in sensitiveness as compared with that at zero frequency. (This fact was not mentioned by Wente as it was believed to be due to experimental error; but the theory here given shows that this decrease was a real effect.) According to the gold-leaf calibration, the sensitiveness fell by 74 per cent. from 120 to 160 p.p.s., so that the sensitiveness at 160 p.p.s. was only 1/16.6 that at zero frequency. It seemed improbable to us that there could be such a marked change in the sensitiveness of the instru-

ment over the range from 120 to 160 p.p.s. and consequently the departure of the gold-leaf observations was attributed to an increase in the heat capacity of the gold-leaf in hydrogen which would reduce its sensitiveness as a thermophone element.[1] It is undoubtedly true that the precision of the results obtained with the gold-leaf thermophone below 1,000 p.p.s. is less than for higher frequencies, and also less than the precision of the calibration from 20 to 120 p.p.s., using the heavy platinum thermophone in a large enclosure of air.

The calibration data of Wente, and a computed (theoretical) curve of sensitiveness *vs.* frequency are shown in Fig. 4. In computing the

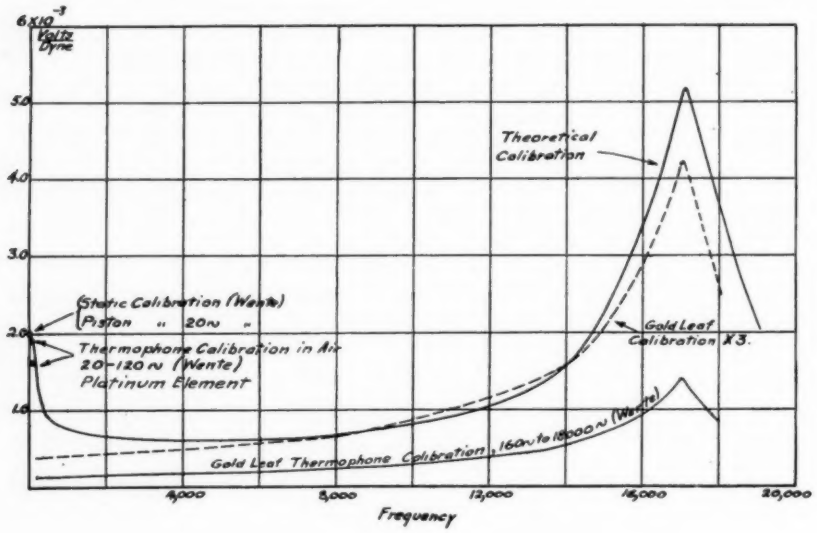


Fig. 4.

Experimental and theoretical calibration of the condenser transmitter. $R = 1.63$ cm. $d = 0.0022$ cm.

theoretical curve, the sensitiveness is taken as proportional to the amplitude of an equivalent system of one degree of freedom, that is,

$$\xi' = \frac{\text{constant}}{\sqrt{\rho^2 n^2 + (mn^2 - s)^2}},$$

in which m, s and ρ are respectively the mass, stiffness and resistance

[1] When this question arose Dr. Arnold and I tried, by simple experiments, to measure any gas that might be absorbed by the gold-leaf element when it was placed in hydrogen, No quantity measurable with our apparatus was obtained. On the other hand, Mr. Wente, experimenting with platinum and gold thermophone elements side by side in the same enclosure, found varying discrepancies between the actual and computed values of sound intensity when the gold thermophone was used. The thermal capacity of the gold-leaf element is at present indeterminate.

coefficients. n is 2π times the frequency. The mass coefficient is of no consequence at low frequencies, but the stiffness and resistance constants should be known.

The stiffness constant at zero frequency (s_0) is the force required to produce unit average deflection (ξ') over the surface of the disc. The tension in the diaphragm was $T = 6.57 \times 10^7$ dynes/cm., and as the average amplitude over the disc was 0.69 times the maximum, we have

$$s_0 = \frac{4\pi T}{.69} = 1.2 \times 10^9 \text{ C.G.S.}$$

The added stiffness due to the air film was computed from (12) for frequencies up to 20,000, assuming that the transmitter behaved like a piston system. The total stiffness (s) is plotted in Fig. 5.

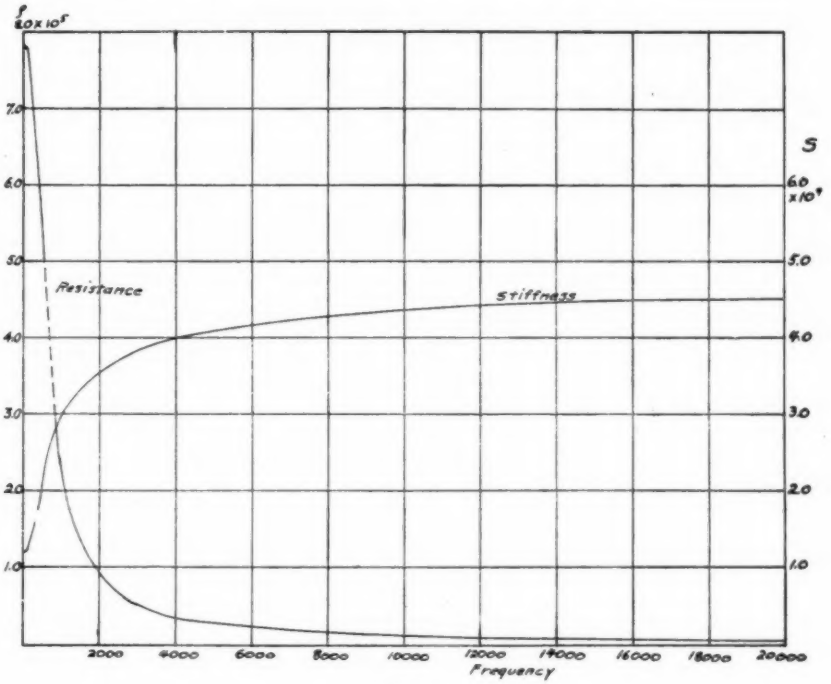


Fig. 5.

Resistance and stiffness factors of condenser transmitter as used by E. C. Wente. $R = 1.63$ cm., $d = 0.0022$ cm.

The resistance constant (ρ) was computed from (11) for frequencies from 1,000 to 20,000. For frequencies from zero to 500 the plotted values are 40 per cent. greater than those calculated from (11). This allowance is made as previously explained, because the membrane main tains its paraboloidal shape in vibrating at low frequencies.

From the stiffness constant at resonance ($s = 4.5 \times 10^9$ at 17,000

p.p.s.) the mass coeffiicent at high frequencies is found to be $m = 0.395$ gram. This is practically the same as if the portion of the membrane directly opposite the disc moved parallel to itself, back and forth, and is a justification of the piston assumption.

Referring again to Fig. 4, the damping coefficient as computed from the shape of the experimental calibration curve near resonance is $\Delta = 5{,}400$. The computed resistance coefficient at resonance is $\rho = 4{,}400$, and this would give a damping coefficient $\Delta = \rho/2m = 5{,}600$. The agreement between theoretical and experimental values of damping shows that the calculated value of resistance is correct, and hence that the scale of sensitiveness on which the theoretical curve is plotted is correct. The theoretical calibration is therefore well established as the true calibration of Wente's condenser transmitter, and the sensitiveness as determined with the gold-leaf thermophone in hydrogen is to be multiplied by a factor of approximately 3 (see the dotted curve in Fig. 4) if it is to agree with the theoretical calibration.

Application of the Theory to Design of the Condenser Transmitter.

For the sake of further insight into the mechanics of the air-damped system, amplitude-frequency curves have been computed for four piston systems having the same mass and low-frequency stiffness, but with variable separation between moving and stationary discs. The constants are

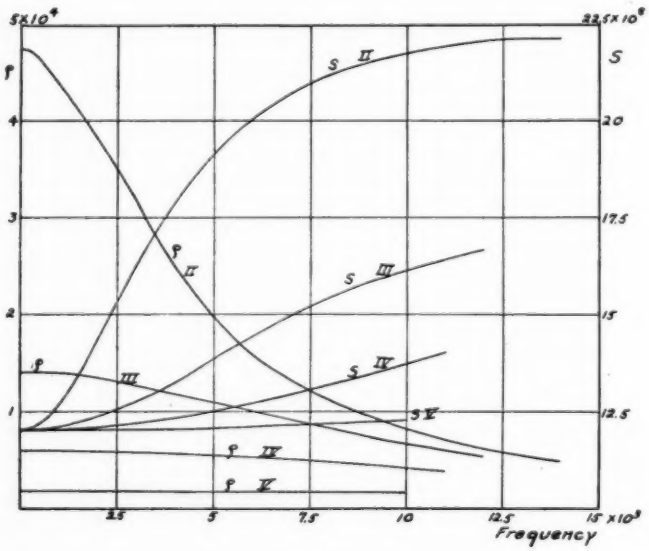


Fig. 6.

ρ and s for four systems of varying separation.

Mass m = 0.40 gram,

Low frequency stiffness, $s_0 = 1.2 \times 10^9$ C.G.S.,

Radius of discs R = 1.63 cm.,

System II, separation d = .005 cm.,

" III = .0075,

" IV = .0100,

" V = .0150,

(Wente's transmitter may be considered as system I of this series.) The resistance and stiffness factors are given in Fig. 6. The amplitude-

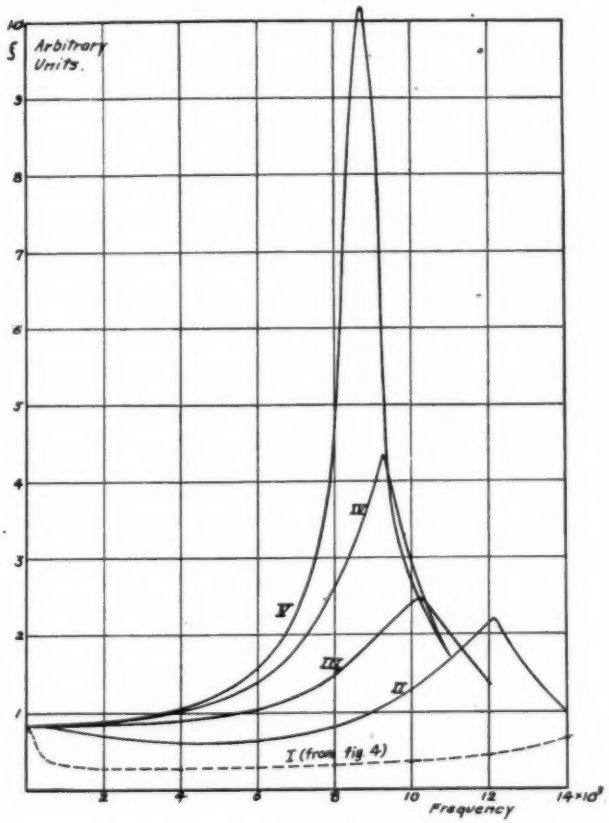


Fig. 7.

Relative sensitiveness at different frequencies for four systems of varying separation.

frequency characteristics are shown in Fig. 7. None of these systems are aperiodic, but they show what can be done with air damping if equal response over different ranges of frequency is desired.

In the condenser transmitter it is not desirable from the standpoint of sensitiveness, to increase the separation between disc and diaphragm

although this would give the system more uniform resistance-frequency and stiffness-frequency characteristics, which properties might be desirable for some work. It seems preferable to make the most of the close adjustment but to facilitate the escape of air from the film by perforating the disc or cutting deep grooves in it, so that the proper combinations of pure resistance and added stiffness is obtained.

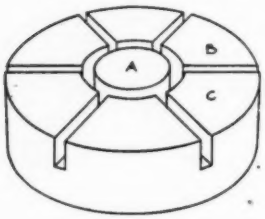


Fig. 8.

In particular, let it be required to design a condenser transmitter whose mass coefficient is 0.40 gram, whose back plate is a disc of radius $R = 1.63$ cm. separated from the diaphragm by a distance $d = .002$ cm., and whose sensitiveness is to be almost rigorously uniform over the frequency range from zero to 8,000 cycles. If the low frequency stiffness is the same as in the several systems considered above, the added resistance and stiffness due to the air-damping should have frequency characteristics somewhere in between those given for systems II and III. For a system having properties intermediate between II and III the ratio of radius of disc to separation should be approximately

$$\frac{R}{d} = \frac{1.63}{.006} = 270,$$

and this condition can only be met with the given separation of .002 cm., by cutting grooves in the disc in such a way that all points in the film are distant less than $R' = 270 \times .002 = .54$ cm. from a low impedance pathway to the open air. Fig. 8 shows one way in which the disc may be grooved to bring this about—the different sections A, B, C of the disc being very closely equivalent to small discs of radius .54 cm. This example should sufficiently illustrate the principle to be followed in designing this type of air-damped vibrating system.

The object of this paper has been to complete as far as necessary the mechanical theory of the condenser transmitter. The mechanism of air-damping has been determined, and formulæ have been obtained from which practical calculations can be made. A complete theoretical calibration of a condenser transmitter has been given which is consistent with the experimental calibration, and which does not disturb the uniform frequency-sensitiveness characteristic of the instrument except at frequencies very near zero. The principles have been given for the design of air-damped systems of maximum damping, and condenser transmitters having rigorously uniform sensitiveness over an extended range of frequencies including zero.

RESEARCH LABORATORY OF THE AMERICAN TELEPHONE AND TELEGRAPH CO. AND WESTERN ELECTRIC CO., INC.

WAVE-LENGTHS OF THE TUNGSTEN X-RAY SPECTRUM.

By Elmer Dershem.

Introduction.

SINCE the X-ray spectra of practically all the available elements had been studied by one investigator or another with results which did not very closely agree and which in general comprised only a few of the principal or most prominent lines, it seemed wise to begin the present investigation with a view to determining more completely and accurately than heretofore the number of lines and their wave-lengths in the spectrum of at least one element. The element most easily tested and the one whose spectrum would be of the greatest value in the X-ray analysis of crystals was tungsten on account of its use as the anticathode of the Coolidge tube, the only type of tube which could be used during the long intervals of time necessary to secure spectral photographs, if the conditions required for the greatest resolving power and the greatest accuracy of measurement were complied with.

The photographic method was chosen for this work in preference to an ionization chamber and electrometer because in the latter method the intensity of the reflected beam must be great enough to give a continuous effect on the electrometer while the photographic plate gives a summation of the intensity of the reflected beam over a time that may be made so very much longer that weak lines have an opportunity to appear.

We shall now consider the factors affecting the accuracy of measurement and resolving power of an instrument using a crystal as a diffraction grating for X-rays. Resolving power is, as usual, defined as the ratio of a wave-length to the smallest difference which may exist between this and a neighboring wave-length and yet have the instrument show that the two waves are separate and not identical. A consideration of these factors will then show that the conditions for the best resolving power are those which lead to a decrease in intensity and would make impossible the securing of sufficient intensity to affect an electrometer under the necessary conditions of a narrow source, great distance from the crystal to the detector and a thin crystal which means less intensity because there are fewer reflecting planes. The theory will also show that the position of the central maximum of the reflected beam is not the true criterion by which the wave-length must be determined but it is instead

the outer edge, which when corrections are made for the width of the source, gives the true measurement. The impossibility of measuring anything other than the central maximum with an ionization chamber eliminates this as a possible accurate method and leaves the photographic plate as the only recourse.

RESOLVING POWER OF A CRYSTAL USED AS A DIFFRACTION GRATING FOR X-RAYS.

In this discussion the assumption will be made that the slit, or source, is the same distance from the crystal as is the photographic plate. In this case, as shown by Bragg,[1] the amount of surface of the crystal exposed to the X-rays makes no difference in the sharpness of the lines since the same wave-length is always reflected to the same point on the plate. This will not be true if the atomic planes are not parallel. In reality the cleavage surfaces of crystals are quite noticeably warped and it is desirable to limit the surface of the crystal exposed to the rays by means of a narrow slit between lead blocks placed close to the crystal even though it does cause a decrease in intensity. It will also be assumed that the crystal is thin enough that the rays may penetrate entirely through the crystal and be reflected from the planes on the back side and again traversing the crystal to reach the photographic plate.

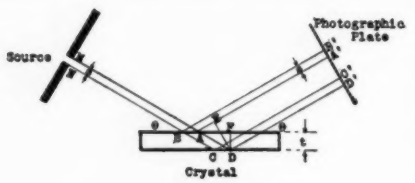


Fig. 1.

With these assumptions as to conditions which may be easily obtained in practice, the question to be determined is, What difference of wave-length is necessary that it may be possible to separate two waves of nearly the same length?

Let the source be a slit of width s at a distance r from the crystal, Fig. 1. Assume that the crystal is in a position to reflect some particular wave-length where $n\lambda = 2d \sin \theta$, in which n is the order of the spectrum, λ the wave-length, d the grating constant or distance between the atomic planes and θ the angle between the incident rays and the crystal surface. Then a ray coming from the side M of the slit may be reflected at A to A' on the photographic plate and a ray from the side N must strike the crystal at the same angle and consequently be reflected at the point B to the point B'. It is easily seen that the reflected rays AA' and BB' are at the same distance apart as the incident rays MA and NB. Hence due to the slit alone a single wave-length would cause a line on the photographic plate the same width as the slit.

[1] Bragg and Bragg, X-Rays and Crystal Structure, G. Bell and Sons, London, 1915.

Considering next the question of the variation of the width of image with the thickness of the crystal, let DE be drawn perpendicular to AA'. Then DE is the width of the reflected beam due to the penetration into the crystal. Let $DF = t$ be the thickness of the crystal. Then $t = AD \sin\theta$ and

$$AD = \frac{DE}{\sin 2\theta}.$$

Then by substitution

$$t = \frac{DE \sin\theta}{\sin 2\theta} = \frac{DE \sin\theta}{2 \sin\theta \cos\theta} = \frac{DE}{2 \cos\theta}.$$

Whence $DE = 2t \cos\theta$.

Since DE is the width of beam due to penetration into the crystal the total width of beam is $s + 2t \cos\theta$, in which s is the width of the slit, or source, t the thickness of the crystal and θ the angle which the incident ray makes with the crystal.

Then $s + 2t \cos\theta$ is the width of the line on the photographic plate. In order to resolve two lines of nearly the same wave-length it is necessary that their images on the plate should not overlap or, in other words, that the centers of their images must be further apart than the width of beam, $s + 2t \cos\theta$.

Assume two wave-lengths, λ and $\lambda + \Delta\lambda$. To find how small $\Delta\lambda$ may be and these wave-lengths still be clearly resolved on the plate. Using the formula $n\lambda = 2d \sin\theta$ let λ take on a small increment $\Delta\lambda$ and θ the corresponding increment $\Delta\theta$. Then by differentiation we have $n\Delta\lambda = 2d \cos\theta\Delta\theta$. This is justified in practice by the fact that $\Delta\theta$ is small in comparison to θ.

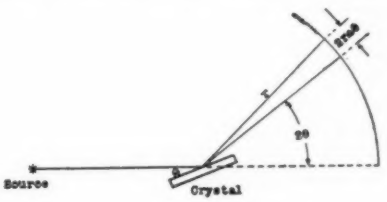


Fig. 2.

According to the above if the crystal is in a position to reflect a wave of length λ it must rotate through an angle $\Delta\theta$ in order to reflect a wave of length $\lambda + \Delta\lambda$ and since the reflected ray rotates twice as fast as the crystal the reflected ray must rotate through the angle $2\Delta\theta$. (See Fig. 2.)

If the distance of the crystal from the plate is r then the displacement of the beam along the plate when the reflecting angle is changed from θ to $\theta + \Delta\theta$ is $2r\Delta\theta$. In order that rays reflected at these angles be separated it is necessary that this distance, $2r\Delta\theta$ be greater than the width of beam $s + 2t \cos\theta$.

$$2r\Delta\theta > s + 2t \cos\theta.$$

But

$$\Delta\theta = \frac{n\Delta\lambda}{2d\cos\theta}$$

and by substitution

$$\frac{2nr\Delta\lambda}{2d\cos\theta} > s + 2t\cos\theta$$

$$\Delta\lambda > \frac{d\cos\theta}{nr}(s + 2t\cos\theta).$$

$\Delta\lambda$ is then the smallest difference between the lengths of two waves that is permissible if the images due to these waves are to be separated on the plate. However the images must be separated by a slightly greater distance in order to leave a clear space between them. Just how much space is necessary for this is not a mathematical problem but a question which must be answered by experience. Probably but little need be added to $\Delta\lambda$ on this account. Neglecting for the time being the question of the necessary space between lines it may be of interest to determine the resolving power under the best conditions that were obtained with the apparatus used in the present work. For example, taking the line in the central part of the L spectrum having a wave-length of 1.241×10^{-8} cm. the experimental values of the quantities contained in the above formula were:

$$s = 0.032 \text{ cm.},$$

$$t = 0.019 \text{ cm.},$$

$$d = 2.814 \times 10^{-8} \text{ cm.},$$

$$r = 62 \text{ cm.},$$

$$\cos\theta = 0.977,$$

$$n = 1.$$

Substituting in the inequality

$$\frac{d\cos\theta}{nr}(s + 2t\cos\theta)$$

the above values of the quantities gives

$$\Delta\lambda > 0.00375 \times 10^{-8} \text{ cm.}$$

Since resolving power is defined as $\lambda/\Delta\lambda$ and for this case λ is 1.241×10^{-8} cm. we have

$$\frac{\lambda}{\Delta\lambda} < \frac{1.241}{.00375},$$

$$\frac{\lambda}{\Delta\lambda} < 331.$$

The resolving power in this case was less than 331, although the experimental values of the width of slit, thickness of crystal and distance to the plate were so chosen as to give the greatest possible resolving power consistent with the necessary requirement of retaining sufficient intensity in the reflected beam to affect the photographic plate in an exposure of a reasonable duration.

It is apparent that the ways in which the resolving power may be increased are to use a higher order than the first, to narrow the source, to decrease the thickness of the crystal and to increase the distance between the crystal and the plate. To do any one of these things tends to decrease the intensity and make necessary a longer exposure and this is not altogether desirable, as it gives the latent image an opportunity to spread and blurr the image and also increases the liability to fogging of the plate due to stray radiation. An increase of distance from crystal to plate decreases the intensity by absorption in the air and this may be a factor of considerable importance in working with the longer wave-lengths. Therefore at present it would not seem possible to so greatly increase the resolving power of a crystal used as a diffraction grating for X-rays as to make it at all comparable to the resolving powers of the grating or echelon used for ordinary light.

From this theory it may be seen, by reference to Fig. 1, that the true angle of reflection must be determined by measuring the position of the outer edge or most deviated portion of the spectral line and subtracting one half of the width of the source from this. This will eliminate any error of measurement due to penetration into the crystal but the crystal must be thin if two nearly equal wave-lengths are to be separated.

METHODS OF APPLYING THE THEORIES CONCERNING RESOLVING POWER.

Since it was the object in this work to make as accurate measurements of the wave-lengths as possible the apparatus and methods of using it will be described somewhat in detail.

The previous theory requiring the use of a thin crystal, the following method of securing and mounting one was adopted. A crystal of rock salt having a perfect cleavage face of about one square centimeter area was chosen and this was fastened face down onto a glass surface by the use of a wax especially prepared for the purpose by mixing Canada balsam and hard sealing wax in such proportions as would give a wax that was hard and tough at ordinary temperatures but which became a thin liquid when slightly heated. After the crystal was firmly cemented to the glass by pressing the two together while warm with a small quantity of wax between and allowing them to cool, the crystal was ground away

until a thickness of not more than 0.019 cm. remained. It was found by experience that attempts to make the crystal thinner than this resulted in causing the crystal to crack and become useless.

The measurements of the position of the lines on the photographic plates were made with a Societa Genevoise dividing engine which was guaranteed by the makers to be accurate to 0.01 mm. in a total length of 40 cm.

To check against possible variations in the pitch of the screw the plates were measured a number of times and each time the setting was changed so that the measurement would be made by a different part of the screw. However the principal object of repeating the measurements was to compensate for the errors of setting by securing a number of readings and averaging the results.

A number of different methods of securing accurate settings of the dividing engine were tried and the one giving the most consistent results was the following. An achromatic combination lens of $1\frac{1}{2}$ inches diameter was placed in a tube 22 inches long. Two parallel hairs were placed at one end of the tube and brought very close to the photographic plate so that the parallel hairs and the spectral line on the plate should be practically in one conjugate focal plane of the instrument at the same time. The spectral line and the parallel hairs were then viewed through a peep hole at the other end of the tube which was near the other conjugate focus of the lens. Owing to the great length of the tube as compared to the distance between the parallel hairs and the photographic plate there was very little parallax and owing to the large diameter of the lens the field of view was large enough to avoid to a considerable extent the loss of contrast that comes from magnifying a small section of surface which shades gradually from one portion to another. It is this difficulty that makes it impossible to use the ordinary microscope having a small objective. To secure proper illumination the apparatus was placed so that the observer looked through the plate toward a clear sky.

Whenever two objects are very close together they appear to blend into one, especially if the edges are not sharp and clearly defined. Owing to this effect as the photographic line approaches the parallel hairs of the microscope it blends with them while not really coinciding with them. To avoid as far as possible, the inaccuracies due to this effect, small dots were made with the point of a needle as nearly as possible along the outer edge of the line and it was then possible while the line was in the field of view of the microscope and yet not too close to the parallel hairs to choose the particular dot which most nearly denoted the position of the edge of the line and then take the measurement when this dot came exactly between the parallel hairs.

DESCRIPTION OF APPARATUS USED IN SECURING THE X-RAY SPECTRUM.

The apparatus used in this work can perhaps best be described by referring to the isometric drawing of the framework, Fig. 3.

The mechanism was enclosed in a box lined with sheet lead $\frac{1}{8}$ inch thick in order to cut out stray radiation, but for simplicity this is not shown in the drawing. The crystal was mounted on the rotating axis A which was fitted with adjustable bearings such that this axis could be made truly vertical with respect to the horizontal plane of the instrument. Between the source and the crystal, as close as possible to the latter, a vertical lead plate $\frac{1}{2}$ inch thick was placed. This is not shown in the drawing. The area of crystal surface upon which the X-rays might strike was limited by a slot 3 mm. wide cut through the center of this plate.

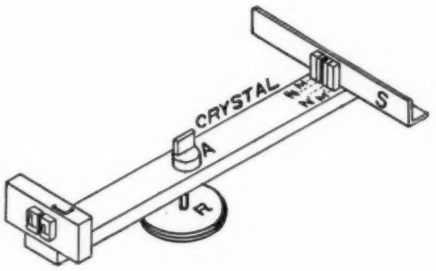


Fig. 3.

One end of the framework of cast iron and steel carried the block of lead L which was about 2 inches thick and of sufficient area to subtend a solid angle at the anticathode of the X-ray tube greater than that subtended by the photographic plate and in this way served to protect the plate from the direct radiation of the tube. The previously mentioned lead-lined box enclosing the apparatus served to protect the plate from the radiation reflected from the walls of the room. A slot about 3/16 inches wide was cut through the center of this block of lead and this slot was covered by the two lead plates or jaws P and P' which had their inner surfaces plane polished and which could be set at any distance apart by means of gauges placed between their upper and lower edges. The slot or space between these two surfaces could then be considered as the source of the X-rays, since it was sufficiently close to the focal spot of the target that this spot subtended a larger angle at the slit than did the crystal, the latter being comparatively far away.

The other end of the framework carried a bar of angle steel, the vertical surface S of which was planed true and then set accurately at right angles to the line joining the center of the source and the center of the rotating axis on which the crystal was mounted. The photographic plate was placed in a light-proof envelope and clamped tightly to this surface and since the distance of the surface from the center of rotation of the crystal could be accurately determined by means of a bar of adjustable length which could later be measured on the dividing engine, it was

possible to determine the distance of the film from the center of rotation by subtracting the thickness of the plate and the paper back of the plate from the measured length of the bar.

The mechanism for holding the crystal is shown in Fig. 4. One side of the shaft A was plane surfaced as was also the block of brass F and these could be firmly clamped together by the two screws H and K. These surfaces could then be separated and placed together at will, always fitting together in the same position. The block F carried the block E attached to it by three screws in such a way that the surface BC could be adjusted to the desired plane and then locked there by the pressure of the screw I. With the shaft set in its bearings the upper and lower parts of the surface BC were adjusted until when viewed through a microscope both the upper and lower edges remained in the axis of rotation as the shaft was rotated. Then this surface BC would contain the axis of rotation and by pressing a crystal surface against this face plate and waxing firmly from behind, the crystal surface would also contain the axis of rotation. The face plate could then be removed by taking out the screws H and K and the crystal would be left properly mounted.

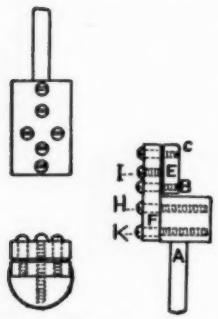


Fig. 4.

The axis A was made perpendicular to the framework by first placing a piece of silvered glass in the position of the crystal and adjusting the bearings until the image of a straight horizontal line drawn along the middle of the surface S was projected back onto the line at all points as the axis was rotated. When these adjustments were made it was assured that the axis of the shaft bearing the crystal was perpendicular to the horizontal plane of the instrument and that whenever a crystal face was placed against the removable face plate its surface would also contain the axis of rotation. The only other adjustment was to set the apparatus as a whole so that the slot between the jaws P and P' was on the straight line joining the focal spot and the axis of rotation of the crystal.

It was necessary to have a precise reference line marked on the photographic plate near the point where the undeviated portion of the X-ray beam would strike in order that a photograph might be taken with the crystal set to reflect toward one side of the apparatus and later one taken on another plate with the crystal turned to reflect to the other side of the center line. From these two plates the mean distance of any particular spectral line from this reference line could be found and having once

determined the position of this reference line with respect to the true center it was possible to determine the true deviation of any wave-length from a photograph taken on one side of the instrument. To check against changes of position the instrument was frequently calibrated by taking photographs on both sides of the center. The reference line was made by allowing part of the portion of the X-ray beam which passed undeviated through the crystal to pass through the narrow slot between the two plane surfaced lead bars N and N' which were soldered to the brass bars M and M' for the purpose of strength and stiffness. These lead surfaces were separated by thin strips of paper between their upper and lower edges and the narrow beam of X-rays that passed through marked a very fine line on the plate.

While the photographs were being taken the crystal was slowly rotated by means of a fine wire which extended from the pulley R, Fig. 3, to a lever which was connected to a float in a tank of water. Water was siphoned into this tank from another tank in which the level was maintained constant and by regulating the rate of flow, the rate of rising of the float, and the rotation of the crystal could be regulated to any value desired.

While taking the photographs of the L radiation the current for the Coolidge tube was supplied by a transformer excited directly from the 110-volt alternating current mains. The transformer stepped the voltage up to a maximum potential of 58,000 volts and the tube rectified its own current, a well-known property of the Coolidge tube provided, as in this case, that the temperature does not become too high.

In order to avoid the necessity of remaining in the room during the long time required for taking the spectral photographs a motor-operated rheostat was placed in the heating circuit of the Coolidge tube and the motor controls were placed in another room. A wattmeter in this room indicated the power input to the transformer and it was possible by regulating the heating current of the tube to secure any power input desired. It was found that when the heating current was such that the power input of the transformer was 240 watts the target remained at a cherry red heat but did not get hot enough to cause damage to the tube. Of this power about 100 watts went to supply the losses in the transformer and the remaining 140 watts represented the power actually used in the tube.

For the K radiations the same method was followed except that the applied maximum potential was raised to 80,000 volts and the current through the heating circuit was set at such a value as to cause the tube to take 140 watts from the transformer as before.

It was found that the power input would remain constant for an hour to within five or ten watts, hence it was possible to work at other things during the long time of exposure required and thus the labor was very much reduced.

EXPERIMENTAL RESULTS FOR THE *L* RADIATIONS.

Some writers on this subject have used the first letters of the alphabet to designate the shorter wave-lengths and others have used these same letters to indicate the longer wave-lengths, while others have used Greek letters. Owing to these confusing methods of nomenclature it has been thought wise to submit the following means of identifying each particular wave-length. The first three significant figures denoting the wave-length in Ångström units are used as subscripts to the Greek letter λ which is usually used to denote a wave-length. If the knowledge of X-ray spectra shall increase to that point where three figures no longer distinguish two neighboring wave-lengths it will be possible to use four or more figures.

In the experimental work a number of photographs were taken using different distances from the crystal to the plate, always keeping the distance from the source to the crystal as nearly as possible equal to this distance. The method of procedure is shown by the following example. Plate No. 104 was placed so as to register the center line and the spectrum on the left side. Later Plate No. 105 was similarly placed on the right side, each being given an exposure of more than twenty-four hours. When measured on the dividing engine the distance of the most deviated side of the spectral line $\lambda_{1.27}$ from the central reference line was found to be 29.99^3 cm. to the left on Plate No. 104 and 30.03^9 cm. to the right on Plate No. 105. The reference line was therefore one half of the difference or 0.023 cm. to the left of the true center. This correction could then readily be applied to photographs taken later on only one side of the apparatus. The deviation of the outer edge of this spectral line was therefore 30.01^6 cm. and since the slit width was 0.032 cm. subtracting one half of this according to the previous theory gives the true deviation of the line to be 30.00^0 cm. The distance from the axis of rotation of the crystal to the plateholder was 61.10^0 cm., from which must be subtracted the thickness of the plate 0.260 cm., also the thickness of the paper envelope enclosing it, which was 0.013 cm., giving 60.82^7 cm. as the distance from the film side of the plate to the axis of rotation. The quotient of the distance from the center to the spectral line divided by the distance from crystal to film gives the tangent of twice the glancing angle of reflection and denoting this angle by θ we have

$$\text{Tan } 2\theta = \frac{30.00^0}{60.82^7}.$$

Whence $\theta = 13^0\ 7'\ 35''$, from which by the use of the formula $n\lambda = 2d \sin \theta$, in which n is unity and d has the value 2.814×10^{-8} cm. We find λ to be $1.278^1 \times 10^{-8}$ cm.

TABLE I.

Summary of Results for The L Radiations Wave-Lengths $\times 10^{-8}$ *Cm.*

Line.	Plates 104 and 105.	Plates 115 and 117.	Plate 121.	Plate 122.	Plate 123.	Average.
$\lambda_{1.48}$				1.4820	1.4836	1.482^8
$\lambda_{1.47}$			1.4719	1.4725	1.4723	1.472^2
$\lambda_{1.41}$					1.4163	1.416^3
$\lambda_{1.29}$	1.2979		1.2968	1.2976	1.2983	1.297^7
$\lambda_{1.28}$					1.2868	1.286^8
$\lambda_{1.27}$	1.2781	1.2781	1.2780	1.2784	1.2793	1.278^4
$\lambda_{1.25}$	1.2589	1.2580	1.2588	1.2593	1.2598	1.258^6
$\lambda_{1.24}$	1.2418	1.2412	1.2413	1.2414	1.2421	1.241^6
$\lambda_{1.22}$				1.2205	1.2199	1.220^2
$\lambda_{1.20}$				1.2102	1.2094	1.209^8
$\lambda_{1.17}$					1.1773	1.177^3
$\lambda_{1.12}$				1.1297	1.1286	1.129^2
$\lambda_{1.09}$	1.0948	1.0951	1.0948	1.0955	1.0963	1.095^3
$\lambda_{1.07}$					1.0705	1.070^5
$\lambda_{1.06}$	1.0645	1.0649	1.0643	1.0645	1.0656	1.064^8
$\lambda_{1.05}$	1.0587	1.0586	1.0581	1.0587	1.0593	1.058^7
$\lambda_{1.04}$					1.0427	1.042^7
$\lambda_{1.02}$	1.0250	1.0246	1.0258	1.0250	1.0262	1.025^3
$^1\lambda_{.91}$	.9153	.9153	.9158	.9165	.9171	$.915^9$
$\lambda_{.70}$				.7058	.7079	$.706^8$
$^2\lambda_{.48}$	.4835	.4838	.4838	.4828	.4838	$.483^3$

[1] Wave-lengths shorter than λ .91 are selectively absorbed by the bromine in the plate causing a dark band at the position of this wave-length.

[2] The silver of the plate selectively absorbs wave-lengths shorter than λ .48 thus causing dark band at the position of this wave-length.

In a similar way the angles of reflection and the wave-lengths were determined for the other characteristic L rays and the results of five separate tests are recorded in Table I. These results were computed from an average of eight separate measurements of each plate. The agreement between the different tests is a fair test of the accuracy of the work since the distances to be measured were different in each case. Table II. gives a summary of the results of different investigators each of whom had either used rock salt crystals directly or had compared the gtating constant of some other crystal with that of rock salt so that in every case the results are based on the value of 2.814×10^{-8} cm. for the

TABLE II.

Tungsten X-Ray Wave-Lengths in Ångström Units as Determined by Different Investigators.

Moseley, Phil. Mag., Vol. 27.	de Broglie,[1] Comptes Rendus, Jan., 1914.	Barnes, Phil. Mag., Sept., 1915.	Gorton, Phys. Rev., Feb., 1916.	Hull, Proc. Nat'l. Acad., May, 1916.	Compton, Phys. Rev., June, 1916.	Siegbahn and Friman, Phil. Mag., July, 1916.	Ledoux-Lebard and Dauvillier, Comptes Rendus, April 30, 1917.	Dershem.
			a_1, Faint, 1.477	a', 1.480	l, 1.5044	α_2, 1.481	9 1.504, Very weak	$\lambda_{1.48}$ 1.482[8], Weak
1.486	Strong ray, 1.471	1.477, Strong	a, Strong, 1.465	a, 1.468	k, 1.4993	α_1, 1.471	8 1.492, Intense	$\lambda_{1.47}$ 1.472[2], Strong
								$\lambda_{1.41}$ 1.416[3], Very faint
					i, 1.3543, Line uncertain			
		1.312, Weak	b_1, Faint, 1.290	b', 1.300	i, 1.3160	β_4, 1.296	7 1.309, Very intense	$\lambda_{1.29}$ 1.297[7], Medium
			b_2, Very faint, 1.283					$\lambda_{1.28}$ 1.286[8], Very faint
	Intense doublet							
	Second ray, 1.279	1.296, Strong	b, Strong, 1.277	b, 1.280	h, 1.2962, Strong	β_1, 1.278	6 1.290, Very intense	$\lambda_{1.27}$ 1.278[4], Strong
	Intermediate, 1.258	1.277, Weak	c, Faint, 1.255	c, 1.260	g, 1.2771	β_3, 1.258	5 1.269, Very intense	$\lambda_{1.25}$ 1.258[6], Medium
	First ray, 1.241	1.258, Strong	d, Strong, 1.238	d, 1.242	f, 1.2587, Strong	β_2, 1.241	4 1.250, Very intense	$\lambda_{1.24}$ 1.241[6], Strong
					e, 1.2349			$\lambda_{1.22}$ 1.220[2], Very faint
								$\lambda_{1.20}$ 1.209[8], Very faint
								$\lambda_{1.17}$ 1.177[3], Very faint
								$\lambda_{1.12}$ 1.129[2], Weak
	Strong ray, 1.096	1.113, Strong	g, Strong, 1.095	g, 1.100	d, 1.1107, Strong	γ_1, 1.095	3 1.101, Intense	$\lambda_{1.09}$ 1.095[3], Strong
								$\lambda_{1.07}$ 1.070[5], Faint
				h { 1.073	c_2, 1.0796 } Line	γ_2, 1.064	2 1.067, } Weak	$\lambda_{1.06}$ 1.064[8], Medium
		1.083, Weak	h, Medium, 1.057	1.065	c_1, 1.0725 } very close double	γ_1, 1.058	1 1.062 } doublet	$\lambda_{1.05}$ 1.058[7], Medium
			k, Medium, 1.024	k, 1.0387	b, 1.0539, Line somewhat doubtful			$\lambda_{1.04}$ 1.042[7], Very faint
								$\lambda_{1.02}$ 1.025[3], Medium
	Second band weak, .9192				a, 1.0387			$\lambda_{.91}$ .915[9], Bromine absorption line
	First band (strong,..... .4823							$\lambda_{.70}$ .706[8], Medium
								$\lambda_{.48}$ .483[2], Silver absorption line

Above table illustrates the various methods of nomenclature adopted by the different investigators as well as the values which they have obtained for the different wave-

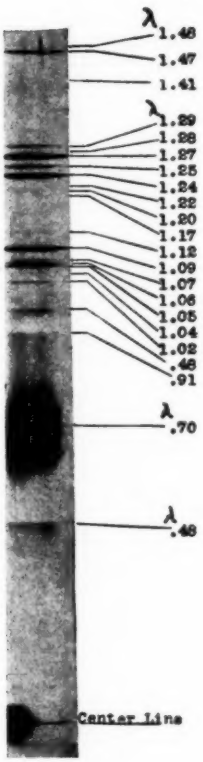


Fig. 5.

Showing the position of the 19 lines of the *L* group and also the boundaries of regions of greater blackening of the plate corresponding to wave-lengths of .9159 and .4833 Ångström units which are due to selective absorption by the bromine and silver of the plate of waves just shorter than their own *K* radiations. (de Broglie, Comptes Rendus, Vol. 158, p. 1493, and Vol. 163, p. 87; Wagner, Annalen der Physik, Vol. 46, p. 868.)

Lines λ .48 are *Ag* absorption lines, the upper one being first order, the lower one second order. Line λ .91 is Br absorption line.

Fig. 6.

ELMER DERSHEM.

distance between the atomic planes in halite. Fig. 5 is a photograph showing the position of the L lines of the tungsten spectrum.

Before doing the preceding work it was thought possible that the distance between planes of atoms in a crystal might not be identical for all crystals of the same substance but might vary with the conditions of growth of the crystal. To test this some preliminary measurements were made using crystals of halite obtained from different parts of the earth. The results showed that to within the limits of error of measurement there was no variation of the grating constant.

Experimental Results for the K Radiations.

In securing the photographs of the K radiations the same methods were followed as in the case of the L radiations except that a higher potential was required. On account of the great penetrability of these rays the use of a thin crystal was much more imperative. Fig. 6 shows a photograph of the four K lines of tungsten. Owing to the use of a thin crystal these lines are all clearly separated in the first order. Other observers using a thick crystal have found difficulty in separating the two lines of shortest wave-length in the first order. Table III. gives the results of four tests for the wave-lengths of the K lines of tungsten and

Table III.

The K Radiations of Tungsten.

Wave-Lengths in Ångström Units.

	Plate 58.	Plate 109.	Plate 114.	Plate 119.	Weighted Average.
$\lambda_{.21}$	.2121	.2126	.2118	.2126	.212[4]
$\lambda_{.20}$	.2075	.2075	.2069	.2078	.207[6]
$\lambda_{.18}$	.1833	.1818	.1831	.1837	.183[4]
$\lambda_{.17}$	.1784	.1786	.1778	.1785	.178[4]

Table IV.

A Comparison of the Results obtained by Different Investigators of the K Radiations of Tungsten.

Wave-Lengths in Ångström Units.

de Broglie, Comptes Rendus, April, 1916.	Hull, G. E. Review, July, 1916.	Ledoux-Lebard and Dauvillier, Comptes Rendus, December, 1916.	Dershem.
α_K .2032	α .212	α_1 .2128	$\lambda_{.21}$ .212[4]
	α .208	α_2 .2053	$\lambda_{.20}$ .207[6]
β_K .1768	β .185	β_1 .1826	$\lambda_{.18}$ .183[4]
		β_2 .1768	$\lambda_{.17}$ .178[4]

Table IV. gives a comparison with the results of other observers. In Table III. in finding the weighted average the last plate is assigned a weight of three and the others a weight of unity since they were not so perfect as the last. In these tests the distance from crystal to plate varied slightly for the different plates, but was always between 60 and 61 centimeters.

ACCURACY OF THE MEASUREMENTS.

Since the extreme variation from the mean value is not greater than 0.1 per cent. for any characteristic line of the *L* group the probable error is less than this amount. In the same way the probable error for the *K* lines is less than 0.8 per cent. On account of the smaller angles these cannot be so easily measured as the *L* lines.

There is very little possibility that the lines observed may in part be due to impurities in the tungsten target. I have no direct information in regard to the purity of the latter but understand that no impurities can be shown by chemical analysis.

These results agree well with such results as are reported by Siegbahn and Friman and also with those computed from the values of the reflection angles as given by de Broglie but disagree with most of the others. This is to be expected in some cases. Gorton used a film wrapped onto a cylindrical surface. It would seem possible that the film might either shrink or stretch in the process of development. Compton recorded the deflections of an electrometer photographically on a moving film. This gives a graphical representation of the relative intensities of the different lines but it would be difficult to get a precise measurement of wave-length in this way since the angular position of the crystal is not accurately known at the moment when the electrometer deflection is being recorded by the photographic film.

THEORETICAL CONSIDERATIONS.

Considerable work has already been done, notably the work of Moseley,[1] in correlating the X-ray spectra of the different elements but little progress has been made toward determining whether, or not, the lines of a single element might be grouped into series such as some of the spectral lines in ordinary light are grouped to form the well-known Balmer's series. The theoretical work of Bohr[2] shows that these series in the case of some of the lighter elements may be derived from a theory of atomic structure and it is the belief of many that X-rays are to the

[1] Phil. Mag., Vol. 26, pp. 1024–34, and Vol. 27, p. 703.

[2] Phil. Mag., Vol. 26, pp. 1–25, pp. 476–505, and pp. 857–75.

heavier elements what light rays are to those of lesser atomic weight. If X-rays are produced by the change of motion of electrons near the central nucleus it might be possible to work back from an empirically derived series to the mechanism by which these rays are excited. So far such a series has not been found, but this may easily be due to the fact that so far only a comparatively small number of lines has been found. The failure to find them is more probably due to a lack of resolving power rather than to the existence of but few lines. In the case of the plate giving 19 lines in the L group the resolving power was less than 170 and we know that with such low resolving powers we would have learned but little of that which we now know of light spectra.

By the use of Bohr's theory Kossel[1] has attempted to explain the origin of the K and L radiations by assuming several stable orbits of different radii near the nucleus and that the hardest of the K lines is due to the falling of an electron from the outer to the inner orbit. These theories led to the conclusion that the difference in frequency of the two K lines (at the time he wrote the K lines were treated as only two but these are now known to be double lines) should be the frequency of the L line of longest wave-length. This has been said to hold true for a number of elements, but if we take the average wave-length of the K doublets as found in this work we should have

$$\frac{1}{.1809} - \frac{1}{.2100} = \frac{1}{\lambda L}.$$

Whence $\lambda L = 1.30$ instead of 1.48 Ångström units as it should if the theory were correct. This is a greater variation than is permissible, even granting the greatest possible errors in these measurements.

Summary.

1. This work shows that accurate wave-length measurements and the separation of close doublets can only be achieved by limiting the thickness of the crystal and the width of source and making the distance between crystal and photographic plate as great as is practicable with regard to the necessary intensity.

2. The L group of the tungsten X-ray lines by these means is shown to contain at least 19 lines and measurements correct to 0.1 per cent. are given of their wave-lengths. From considerations of the resolving power of the apparatus it seems possible that the true number may be as great as the number of lines in the light spectra of an element.

3. It is shown that the K lines of tungsten may be clearly separated

[1] Ber. d. Physik. Gesel., Vol. 12, p. 953, 1914.

in the first order if the conditions required for the highest practicable resolving power are complied with.

In conclusion I wish to thank the staff of the physics department and especially Professor G. W. Stewart, who directed the work, for many helpful suggestions and encouragement in the carrying out of this task and also to Mr. A. M. McMahon, who gave much assistance in the performance of the work.

PHYSICS LABORATORY,
UNIVERSITY OF IOWA,
December, 1917.

PROCEEDINGS

OF THE

AMERICAN PHYSICAL SOCIETY.

MINUTES OF THE NINETY-THIRD MEETING.

A REGULAR meeting of the American Physical Society was held in South Hall, University of California, Berkeley, on March 30, 1918, at 3 p. m.

Papers were presented as follows:

The Formation of Negatively Electrified Rain Drops. FERNANDO SANFORD.

The Specific Inductive Capacity of Metals. FERNANDO SANFORD.

The Relation of Nuclear Atomic Charges to Serial Numbers. FERNANDO SANFORD.

Note on a Reverse Concentration Cell. FERNANDO SANFORD.

Law of Motion of a Droplet Moving with Variable Velocity in Air. R. B. ABBOTT.

Conditions Affecting the Distribution of Deposit from Cathode Disintegration. I. L. JONES.

Velocity of Waves as Depending on Velocity of Source. DINSMORE ALTER.

The Effects of the Chimes on the Mechanical Vibrations of the Sather Tower. ELMER E. HALL.

An Harmonic Synthesizer Having Components of Incommensurable Period and any Required Decrement. W. J. RAYMOND.

The Experimental Illustration of Harmonic Motion. JOHN C. SHEDD.

Thermo-Couples for Student Use in Calorimetric Work. RALPH S. MINOR.

Demonstration of a Laboratory Wave Model. JOSEPH G. BROWN.

Some Peculiarities of Line Structure in Arc and Furnace Spectra. ARTHUR S. KING.

Equivalent Resistance of an Iron Core and Absorption Resistance of a Condenser. F. J. ROGERS.

About 30 members and visitors were in attendance.

In the evening 22 members dined together at the Faculty Club.

E. P. LEWIS,
Local Secretary for the Pacific Coast.

MINUTES OF THE NINETY-FOURTH MEETING, APRIL 27, 1918.

THE ninety-fourth meeting of the American Physical Society was held in Fayerweather Hall, Columbia University, New York, on Saturday, April 27, 1918. Vice-President Ames presided in the absence of the president, Professor H. A. Bumstead, who is serving as Military Attache at the American Embassy in London. About seventy members and visitors were present.

At the meeting of the Council the following elections took place: *elected to regular membership:* E. D. Williamson; *elected to associate membership:* Thomas F. Ball, R. F. Bichowsky, Martha C. Bolton, L. B. Clark, Charles A. Corcoran, N. W. Cummings, Hugh L. Dryden, Alex F. Feild, Erick Hausmann, Kang-Fuh Hu, G. R. Greenslade, Wm. H. Hoover, C. Moreau Jansky, Jr., Adolph Lomb, Max H. Petersen, Toyoji Shinomiya, Leonard T. Troland, Cletus C. Van Voorhis, Mabel Weil; *transferred from associate to regular membership:* O. E. Buckley, K. T. Compton, Irving B. Crandall, H. L. Dodge, Saul Dushman, A. W. Hull, W. H. Kadesch, J. R. Roebuck, Otto Stuhlmann, L. D. Weld, Frances Wick.

Twenty papers were presented as follows, three being read by title:

The Spectral Photoelectric Sensitivity of Molybdenite. (Read by title.) W. W. COBLENTZ, M. B. LONG, AND H. KAHLER.

Electronic Frequency and Atomic Number. PAUL D. FOOTE.

The Resonance and Ionization Potentials for Electrons in Thallium Vapor. PAUL D. FOOTE AND FRED L. MOHLER.

On the Relation Between the X-Ray Series and the Atomic Numbers of the Chemical Elements. WILLIAM DUANE AND KANG-FUH HU.

The Relation Between the General X-Radiation and the Atomic Number of the Target. WILLIAM DUANE AND TAKEO SHIMIZU.

On the Critical Absorption and Characteristic Emission X-Ray Frequencies. WILLIAM DUANE AND KANG-FUH HU.

Photoelectric Effect at X-Ray Frequencies. KANG-FUH HU.

The Spectra of Hot Sparks in High Vacua. R. A. MILLIKAN AND R. A. SAWYER.

The Law of Symmetry of the Visibility Function. IRWIN G. PRIEST.

A Precision Method for Producing Artificial Daylight. (Read by title.) IRWIN G. PRIEST.

The Photo-Luminescence and Katho-Luminescence of Calcite. (Read by title.) E. L. NICHOLS, H. L. HOWES AND D. T. WILBUR.

Thermionic Amplifier. H. J. VAN DER BIJL.

Increase in Length of Life of Tribolium Confusum, Due to X-Rays. WHEELER P. DAVEY.

A Method for the Quantitative Study of Gases in Metals. H. M. RYDER.

On the Observation of the Apparent Focus of Auroral Streamers. C. C. TROWBRIDGE.

Photograph of an Aurora Model. C. C. TROWBRIDGE.

Meteor-Train Spectra and Probable Erroneous Conclusions of the Observers. C. C. TROWBRIDGE.

The Influence of Amalgamation Variables Upon the Mercury Content and the Crushing Strength of a Dental Amalgam. ARTHUR W. GRAY AND PARIS T. CARLISLE, 4TH.

The Influence of Amplitude and of Electromagnetic Driving on the Frequency of Tuning Forks. DAYTON C. MILLER.

Some Optical Constants of Certain Organic Compounds. H. P. HOLLNAGEL.

DAYTON C. MILLER
Secretary

THERMO-COUPLES FOR STUDENT USE IN CALORIMETRIC WORK.[1]

BY RALPH S. MINOR.[1]

ON account of the difficulty in securing sensitive thermometers for general laboratory use, a variety of thermocouples have been designed for use with a galvanometer and an adjustable resistance so that the galvanometer reading in centimeters equals the temperature difference in degrees C. Both copper-constantan and nickel-iron couples have been used, the choice depending upon the sensitiveness of the galvanometer. Calibration is accomplished by placing one junction in ice and the other in a bath at the temperature of boiling ether, 35° C., and adjusting the resistance until the scale deflection is 1 cm. per degree C.

AN HARMONIC SYNTHESIZER HAVING COMPONENTS OF INCOMMENSURABLE PERIOD AND ANY DESIRED DECREMENT.[1]

BY WILLIAM J. RAYMOND.

IT is known that when two oscillating electric circuits containing inductance and capacity are connected, either by electromagnetic or by electrostatic coupling, under certain conditions the current in each circuit is complex, damped harmonic, each of the two constituents of the resultant oscillation having its own period and decreasing according to the logarithmic law. The oscillation shows recurrent maxima, similar to beats in sound, gradually decreasing as the currents die away. If the first circuit is subjected to some form of impulse excitation, by the "quenched gap" for example, the oscillation of current in the second circuit will quickly reach a single maximum of amplitude and then die away more slowly with its own natural period and logarithmic decrement. Coupled pendulums have been constructed which show the same complexity of oscillation, neither of the constituent periods agreeing with the period of either pendulum, oscillating by itself, and each of the constituent oscillations having its own damping factor. When three pendulums are connected there are in general three diminishing components in the resultant oscillation, although one or two of them may be suppressed by appropriate choice of initial conditions. The three constituent periods differ from the natural, uninfluenced periods of the pendulums and they are in general incommensurable.

[1] Abstract of paper presented at the Berkeley meeting of the American Physical Society, March 30, 1918.

Curves exhibiting these complex oscillations as functions of time may be obtained by means of photography. It has been usual to measure the constants of the coupled systems, such as the inductance, capacity and resistance in each of the electric circuits, and then to construct curves, point by point, computing the ordinates from theoretical equations for comparison with the photographic curves. If there is agreement in all respects it affords confirmation both of the correctness of the measurement of the constants, and of the validity of the equations from which the curves were constructed. One of the purposes of the synthesizer named in the title of this abstract is to draw continuous curves which will show graphically the characteristics of complex harmonic motions. It is hoped that the curves may be drawn with sufficient precision and predetermination of form to serve as a check upon the measurement of the constants of connected circuits or pendulums, as well as to test the applicability of the equations employed. After setting the machine and drawing a curve, any number of ordinates may be obtained without the labor of repeated computations.

In 1906 J. R. Milne[1] described "A New Form of Harmonic Synthetiser" which provided for an incommensurable ratio of the speeds of two components by means of parallel cones connected by a shifting leather belt. The amplitude of one component could be altered while the machine was in motion by a manually operated device, but apparently not according to any predetermined or numerical value of the decrement. A synthesizer, with essential parts to be described briefly, is now being constructed by the mechanician of the department of physics of the University of California. Three parallel shafts carry truncated cones of the same vertical angle, the larger end of one cone opposite the smaller end of the next. Friction wheels transmit the motion from cone to cone, and by setting a wheel at any desired place along the slope of the cones any required ratio of speeds may be obtained, commensurable or incommensurable. Each shaft carries also a shallow, circular box on the cover of which is a projecting, eccentric pin which actuates a slotted cross-head of the usual type. If the pin is at a fixed distance from the center of the box and if the shaft turns uniformly, the motion of the cross-head is simple harmonic. But if the pin is made to move toward the center while the shaft is turning, the motion of the cross-head is damped harmonic, the kind and amount of the damping depending upon the rate at which the pin is moved toward the center. The decrement of the motion may be logarithmic or rectilinear or of any other desired type. To secure the centripetal motion of the pin a cam is placed inside of the box, the cam being actuated by an independent shaft which passes centrally through the hollow shaft which carries the box. The pin is carried by a slide on the cover of the box and projects inwardly through a slot in order to engage with the cam. The curve of the cam and the relative angular velocity of the cam and the box will determine the rate at which the pin is drawn toward the center of the box and consequently the nature of the motion

[1] Proc. Roy. Soc. Edinburgh, Vol. 26, pages 207–233, with plate.

of the cross-head. By the use of a cord passing over pulleys attached to the cross-heads the motions of two or more of them may be compounded and shown graphically by a pen fastened to the cord. The pen draws a transverse trace on a band of paper which is rolled uniformly from one drum to another.

The synthesizer may be used in any one of the following ways: (1) It will draw a simple harmonic curve of any required amplitude and wave-length within the limitations of the construction of the machine. (2) It will draw a damped harmonic curve: (*a*) with a logarithmic decrement; (*b*) with a rectilinear decrement; (*c*) with a decrement corresponding to the motion of an oscillating system damped by resistance proportional to the square of the velocity; (*d*) with a decrement of any other specified type. (3) It will compound two or three simple harmonic curves of the same or different periods, commensurable or incommensurable. (4) It will compound two or three damped harmonic curves of any type and magnitude of decrement, within the limitations of the construction. (5) It will compound simple harmonic and damped harmonic curves. While the present synthesizer is designed to have three components, others may be added if the need arises.

UNIVERSITY OF CALIFORNIA,
March 30, 1918.

VARIATION OF VELOCITY OF WAVES DUE TO MOTION OF THE SOURCE.[1]

BY DINSMORE ALTER, Captain C.A.N.A.

IN Lick Observatory Bulletin 305 was published a hypothesis concerning variable velocity of light and of gravitation. According to this hypothesis the velocity for comparatively short distances is the vector sum of the normal velocity of light or gravitation and the velocity of the source. Certain results of the hypothesis were considered. It was shown that the Michelson-Morley experiment is satisfied; that binary stars are pushed continually farther apart and that their orbits become more excentric. This last is an astronomical phenomenon for which an explanation has been much needed. Beyond outlining the hypothesis and a few of its results, no proof was offered.

Two entirely different sets of experimental data, as well as a theoretical consideration, prove that, contrary to the commonly accepted belief, the velocity of sound is affected by the velocity of the source and does not depend only on the medium as hitherto supposed. The theoretical consideration is based on Poynting's equations as given in the Encyclopædia Britannica, Vol. 25, page 440. All that it has been necessary to add to these is to show that the external pressure mentioned in his equations does exist for a moving source. The experimental proof consisted first of showing that the data collected by Wolf, and quoted in Winklemann's Handbuch der Physik, Band II., seite 523–526, are perfectly satisfied by the theory, and secondly in the fact that the whistling of shells, coming toward the observer at twice the normal velocity of

[1] Abstract of a paper presented at the Berkeley meeting of the American Physical Society, March 30, 1918.

wound was observed by the author, by Private George H. Bardsley, formerly Whiting Fellow in physics in the University of California and by Lieutenant George McFarland, C.A.C., and by numerous other observers at other times.

We have, therefore, two sets of experimental data entirely different from each other, as well as our mathematical theory to assert that the velocity of sound depends upon the velocity of the source as well as upon the kind of medium.

Since our equations have been built from energy relations it can be seen at once that the same reasoning will apply to all waves in any similar medium. If, therefore, we assume a medium similar to air for light, the same reasoning as for sound must apply and the velocity of light will depend upon the velocity of the source. It is interesting to say, in this connection, that the Michelson-Morley experiment, which has been assumed by many to prove that the ether does not exist, becomes, in the light of this theory, one of the strongest proofs of its existence.

The argument against an emission hypothesis for light as obtained from observations of binary stars and quoted by Tolman, Comstock and others do not apply to the variable velocity of light demanded by this work because at a distance of a few light hours from the source the velocity of light will have become sensibly normal.

At short distances, observed results, according to the emission hypothesis, or to this, would be nearly the same in this regard. At the very great astronomical distances, varying all the way from four to thousands of light years, at which binaries are observed, there is a great divergence. The primary postulate of relativity seems to be that it is impossible from observations made in any system to tell which bodies of the system are moving. At astronomical distances this can be done under our hypothesis, and, therefore, it is not relativity.

By analogy we have strengthened the hypothesis for gravitation stated in the earlier paper. The astronomical arguments advanced there seemed fairly strong, even before there was this proof of what seems an analogous case. The perturbations due to this hypothesis should be computed for every possible binary in order to get a certain test as soon as possible.

PHOTOGRAPH OF AN AURORA MODEL.[1]

BY C. C. TROWBRIDGE.

IN order to study the optical effects of perspective produced by the auroral rays, a model of the aurora was constructed covering the larger portion of a room. A large number of strips of paper an inch broad and three feet long were fixed to wires near the ceiling of the room so that they gave an inclination of about 73° with the horizontal. This value was taken as approximate to the supposed dip at a certain station at Lat. 46° N. Photographs of

[1] Abstract of a paper presented at the New York meeting of the American Physical Society, April 27, 1918.

this model show a beautiful apparent focus of the artificial rays in the position corresponding to 17° south of the zenith in the model. When one looks towards the "north" there is another focus below the "northern horizon." When the observer looks towards the "south" the rays do not focus below the horizon. It was explained how the direction of the auroral rays could be determined by means of a surveyor's transit; by examining the slant of the rays in the northern sky.

The most recent and carefully made observations of Störmer and others indicate that the auroral discharge takes place between 55 and 90 miles with a maximum between 60 and 64 miles. The altitudes of 29 meteor trains, the records of which have been collected and classified by the writer, give a maximum at about 60 miles altitude, showing an approximate coincidence between these two zones of the atmosphere of the earth. Both zones depend on the existing gas pressure. The dimensions of the model were therefore based on the latest information as to the height of the auroral streamers.

Professor Elihu Thompson in a recent number of the Transactions of the National Academy of Science argues in favor of a vertical direction of the auroral rays. All data seems to point to the fact that they are not vertical, but are approximately parallel to the magnetic lines of force. The observations in general seem to indicate an anomalous behavior relative to the declination, but the records seem to be fairly consistent with respect to the dip.

ON THE OBSERVATION OF THE APPARENT FOCUS OF AURORAL STREAMERS.[1]

BY C. C. TROWBRIDGE.

THE great aurora of August 26, 1916, which was seen both in England and all over the northern portion of the United States, was observed in Prince Edward Island, Canada, by the writer. The aurora appeared there both in the south and in the north of the heavens, the general appearance being that of a luminous umbrella, showing a clearly defined focus about 2° south of the star Gamma Lyra at the time of observation. From the position of the apparent focus, or radiant point, and the hour, 8:20 p. m. (Atlantic time), and also the latitude and longitude of the place, the altitude and azimuth of the point in the heavens from which the streamers seemed to radiate was computed. The results show the streamers to be within 2° of the magnetic elements of the place. The "inclination" (dip) of the rays was computed to be about 73° 00′ and the "declination" about 22° 40′. There are conflicting theories in regard to the question whether the rays are parallel to the magnetic lines of force or not. Birkeland in his recent treatise points out that the matter is an undecided question.

The only other accurate observation of the focus of the aurora of August 26, 1916, was made by Professor Joel Stebbins, near Frankfort, Michigan. The observation was published in the Journal of the Royal Astronomical Society of

[1] Abstract of a paper presented at the New York meeting of the American Physical Society, April 27, 1918.

Canada for April, and shows that the magnetic dip and the direction of the streamers were almost identical, but that the focus point was 2 1/2° due east of the magnetic zenith.

In the Monthly Weather Review of August, 1916, published in October, seventy-odd descriptions of the aurora of August 26 were given as reported to the Weather Bureau from different stations throughout the United States. About twenty of the observers refer to a focusing of the rays, or a tendency of the rays to focus. In several of the reports the statements are indefinite. In the paper referred to there are quotations from ten of these descriptions in which it is definitely stated that the radiant point or apparent focus of the streamers was anywhere from a few degrees to 15° south or southeast of the zenith. It is a noteworthy fact that the observations with one exception on the Atlantic seaboard mention the radiant point as being east or south, while all those in the central portion of the country give the radiant point as south of the zenith, which is to be expected if the declination of the rays is nearly that of the magnetic needle.

During the summer of 1917, the writer made observations on four evenings, of the apparent focus or radiant point of the aurora overhead. The altitude and azimuth of the focus have been computed in the case of each of the fourteen observations made, and a very close coincidence has been found between the altitude and the magnetic dip or inclination. In the case of the azimuth, considerable variation has been found among observations made at short intervals, these changes in all probability corresponding to sudden changes in the earth's magnetic field due to the violent magnetic storm reported at that time.

METEOR TRAIN SPECTRA AND PROBABLE ERRONEOUS CONCLUSIONS OF THE OBSERVERS.[1]

BY C. C. TROWBRIDGE.

METEOR trains seen at night, or the so-called persistent phosphorescent streaks which are deposited by large rapid meteors are self-luminous. This fact is evident because they occur in the heavens where reflected sunlight is impossible and since the spectra of these trains consist of a few bright lines or bands.

Observations have been made of meteor-train spectra by A. S. Herschel, J. Browning, A. Secchi and N. von Konkoly. Herschel's observations showed a bright yellow line or band and indications also of a faint continuous spectrum in certain cases.

Browning's observations were not very conclusive, but indicate in some trains a "lavender"-colored band.

Secchi observed a train spectrum for ten minutes which was composed of a red, a yellow and a green line (or bands).

Von Konkoly observed a train spectrum for eleven minutes which showed one yellow and one green line (or narrow bands), and also some red and other

[1] Abstract of a paper presented at the New York meeting of the American Physical Society, April 27, 1918.

colors which he thought were caused by coal gas. The most prominent lines or bands were attributed to the yellow of sodium and the green of magnesium and the others to lithium, thallium, coal gas, etc. Apparently no *direct* comparisons were made, by any of the observers as seems to be shown by a study of all the original papers.

It seems impossible with the present knowledge of physics and the evident cold gaseous nature of meteor trains that metallic spectra were observed. A meteor train after ten minutes may readily occupy five or ten cubic miles.

The only possible solution of the questions is that the spectrum was a gaseous one, either a brush-like discharge or more likely a phosphorescent condition of the gas, which the writer considers highly probable.

The visual spectrum of nitrogen in the phosphorescent, or "active" state, consists of very bright yellow and green bands and also several others, chiefly one in the red and one in the blue green more faint.

While at present there is no positive evidence that meteor trains show the spectrum of a gas in the phosphorescent state, there seems to be very great doubt of the possibility that Herschel, Secchi and Von Konkoly saw metallic spectra in the meteor trains they observed.

THE PHOTO-LUMINESCENCE AND KATHO-LUMINESCENCE OF CALCITE.[1]

BY E. L. NICHOLS, H. L. HOWES AND D. T. WILBER.

IN addition to the brief phosphorescence of calcites of the Franklin Furnace variety described in a recent paper[2] these calcites, when subjected to kathodo bombardment, have been found to exhibit phosphorescence which persists for several minutes. The curve of decay of this kathodo luminescence is of the form characteristic of persistent phosphorescence in general, consisting of three successive processes each less rapid than the preceding. The photo-luminescence, on the other hand, as shown in the paper just cited, is of the opposite type, hitherto supposed to be peculiar to the uranyl salts, with three successive processes each more rapid than the foregoing one. We have therefore, as in the case of the uranyl salts[3] two distinct types of phosphorescence according to the mode of excitation. Having followed the kathodo phosphorescence for 300 seconds by the usual well-known method of a single excitation and determined the form of the curve of decay, the relation of this curve to that obtained by photo-excitation is of importance. In the method of single excitation the earliest observation practicable is about .5 sec. after the close of excitation, whereas the entire visible duration of photo-excitation is less than .4 sec.

To obtain observations of the earlier portions of the decay curve for kathodo phosphorescence we devised a special form of disk phosphoroscope workable

[1] Abstract of a paper presented at the New York meeting of the American Physical Society, April 27, 1918.

[2] Nichols and Howes, Am. Physical Soc., Pittsburgh meeting, 1917, PHYS. REV., April, 1918.

[3] Wick and McDowell, PHYS. REV., Vol., XI.. No. 6, p. 421, 1918.

in vacuo with which apparatus it was possible to make measurements for the entire range between .06 seconds and 90 seconds.

In this manner it has been established that the curve for kathodo luminescence is independent throughout in character from that for photo luminescence and is not to be regarded as in any sense a continuation of the latter. The two modes of excitation clearly produce quite different conditions within the phosphorescent material. It has further been shown that kathodo-bombardment does not produce a change in the surface layers such that subsequent photo excitation will cause persistent phosphorescence. The two effects indeed may be superimposed without mutual interference.

A METHOD FOR THE QUANTITATIVE STUDY OF GASES IN METALS.[1]

BY H. M. RYDER.

THE metal studied, in the form of a long strip of small cross section, is mounted on tungsten supports in a bulb surrounded by a water jacket, and is heated by the passage of an electric current, its temperature being determined by the resistance change, or by the use of very small thermocouples. The gases are pumped into a second bulb by a diffusion pump immediately upon being released and then analyzed for O_2, N_2, H_2, CO, CO_2, H_2O, and CH_4, in a glass system at low pressure, separations being made by liquid air and solid CO_2, with provision for the addition of O_2 or CO which reacts with the H_2, CO, CH_4, or O_2 in a small combustion bulb, a platinum filament being used for ignition. Quantities of gas as small as 1 mm.^{3} equivalent at atmospheric conditions can be analyzed quantitatively with a probable error of not more than 5 per cent. The amounts of CO_2, CO, H_2O, O_2, H_2, and N_2 given off from a specimen of silicon steel in each 50 degree step from 20° C. to 1000° C. are given.

WESTINGHOUSE RESEARCH LABORATORY,
EAST PITTSBURGH, PA.,
April, 1918.

THE RESONANCE AND IONIZATION POTENTIALS FOR ELECTRONS IN THALLIUM VAPOR.[1]

BY PAUL D. FOOTE AND FRED L. MOHLER.

THE resonance and ionization potentials for electrons in thallium vapor have been measured by the method described in earlier papers, with the modification of the use of a hot equal-potential surface instead of a hot wire as a cathode. The cathode was similar in principle to that used by Goucher and consisted of a platinum (or better, a nickel cylinder) insulated from a helix of tungsten wire, inside, which was used as the heater. The entire apparatus was mounted inside a glazed porcelain tube and heated to about 900° C. At this temperature all parts of the ionization chamber show ther-

[1] Abstract of a paper presented at the New York meeting of the American Physical Society, April 27, 1918.

mionic emission, so that the measurements are attended by leakage difficulties which were not present in the work with other metals and hence the accuracy obtained in earlier work is not to be expected. The pressure as measured by a McLeod gauge was less than 0.002 mm. Hg. Ionization could be detected at temperatures as low as 700° C., but resonance did not appear until the vapor density was considerably higher, corresponding to about 900° C. Ionization was accompanied by a strong emission of green light, undoubtedly the complete line spectrum in which the line 5351 stands out most prominently, Inelastic collision of the resonance type occurred at multiples for the applied accelerating potential of 1.08 volts. Ionization occurred at an applied potential of 6.6 volts, which when corrected for the initial velocity, observed as 0.7 volt, gives the final value for the ionization potential of 7.3 volts. The thallium spectrum is characterized by a set of doublet series. The resonance potential of 1.08 volts is given within experimental errors by the quantum relation $h\nu = eV$, where ν is the frequency of the stronger line ($\lambda = 11513$) of the first doublet of the principal series, sometimes denoted by $\nu = 2.5\ s - 3p$. The theoretical value of the resonance potential computed on this basis is 1.07 volts. We believe this is good evidence that the single-line spectrum of thallium is $\lambda = 11513$.

We were unable to detect any signs of ionization accompanying resonance or any resonance due to the line $\lambda = 13014$. If thallium acted in a manner similar to sodium or potassium, one would expect from the analogous relations in the series of these elements to find ionization determined by the quantum relation $h\nu = eV$, where ν is the limit of the principal series $\nu = 22786$. This requires a value of $V = 2.81$ volts which cannot be considered in the light of the experimental data. We believe that our work enables the prediction of a new series in thallium. It is very possibly of the form $\nu = 1.5S - mP$, a single-line series converging at $1.5S$ lying between 57000 and 60000. The highest convergence frequency of any series so far known for thallium is 49263. The present work again brings up the question of the separate excitation of lines constituting a doublet. Thallium appears to offer a fruitful field for work in this regard.

BUREAU OF STANDARDS,
WASHINGTON, D. C.,
April 10, 1918.

ELECTRONIC FREQUENCY AND ATOMIC NUMBER.[1]

BY PAUL D. FOOTE.

EXCEPTION is taken to the theory proposed by Dr. Allen relating electronic frequency and atomic number, described in three recent papers appearing in Phil. Mag. and Proc. Roy. Soc. London. The present article is given in the PHYS. REV., 1918.

ON THE RELATION BETWEEN THE K X-RAY SERIES AND THE ATOMIC NUMBERS OF THE CHEMICAL ELEMENTS.[1]

BY WILLIAM DUANE AND KANG-FUH HU.

MANY attempts have been made to find some characteristic of the chemical elements that would increase by equal amounts in passing from one element to the next.

Moseley's classical experiments show that the square roots of the frequencies ν of corresponding lines in characteristic X-radiation are almost, but not quite, linear functions of the atomic numbers.

Recent researches confirm this, and indicate that the jump in the value of the square root of the frequency in passing from one element to the next increases with the atomic number, the curves representing $\sqrt{\nu}$ as functions of N bending slightly upward.

It might be expected that the critical absorption frequency in the K X-ray series would bear the simplest relation to the atomic number, for it appears to be the most important frequency characteristic of an element. Its importance rests upon the following facts. The frequency is (*a*) the critical absorption frequency; (*b*) the critical ionization frequency (this probably means critical frequency for the emission of electrons with definite energy); (*c*) the frequency for which the equation $Ve = 1/2\ mv^2 = h\nu$ holds ($1/2\ mv^2$ being the energy of the electron required to produce the K series); (*d*) the highest frequency known to be characteristic of the element [It lies very close to the highest emission frequency, if any thing slightly (1/5 per cent.) above it].

Mr. F. C. Blake and one of us last year measured the critical absorption frequencies for most of the elements from bromine ($N = 35$) to cerium ($N = 58$) and found that they approximately obey the law, $\nu = \nu_0 (N - 3.5)^2$, in which ν_0 is the Rydberg fundamental frequency. There appears to be a small systematic variation from this law, however.

We have extended these critical absorption measurements recently, so that we now have most of the critical absorption frequencies from manganese ($N = 25$) to cerium ($N = 58$), all measured with the same apparatus. In order to measure the lower frequencies we used a specially designed X-ray bulb with a long glass side tube carrying a thin glass window at its end and extending out toward the X-ray spectrometer. This markedly reduced the absorption of the X-rays by the glass and the air.

The results confirm those obtained last year. The $\sqrt{\nu}$ is not quite a linear function of N.

It is interesting to inquire whether some other characteristic of the X-radiation might not be a linear function of the atomic number.

Calculating the velocity v of the electron required to produce the K radiation from equation (1) we find that it is accurately represented by the equation

$$v = v_0 (N - 1.5), \qquad (2)$$

[1] Abstract of a paper presented at the New York meeting of the American Physical Society, April 27, 1918.

in which $v_0 = .006780 \times c$ (c = velocity of light). None of our measurements differs from the value given by this equation by as much as 1/5 per cent., and there does not appear to be any systematic variation from the linear relation.

This equation (2) also represents the velocity required to produce the K X-radiation of the elements calculated from the highest frequencies recorded in Siegbahn's tables as far as, and including magnesium ($N = 12$). Further it gives the velocity required to produce the K radiation of tungsten calculated from Hull's data.

That this critical velocity should be a linear function of N—*i. e.*, should increase by equal amounts from one element to the next, appears extraordinary. It would seem to indicate that some of the fundamental laws connecting X-radiation with other characteristics of the chemical elements represent velocity relations and not momentum or energy relations.

On the Critical Absorption and Characteristic Emission X-Ray Frequencies.[1]

By William Duane and Kang-Fuh Hu.

It is well known that a marked change in the absorption of X-rays by one of the chemical elements occurs in the neighborhood of the emission lines of the K-series of that element.

Last year Professor F. C. Blake and one of us[2] measured the critical abosorption wave-lengths (λ_a) for most of the elements from bromine to cerium, both inclusive, estimating the error of measurement at about 0.1 per cent. These wave-lengths differ from the shortest emission wave-lengths in the K-series of the elements that have been measured by considerably more than 0.1 per cent.

To determine, if possible, whether there is a real difference between the critical absorption wave-length (λ_a) and the wave-length (λ_γ) of the γ line in the emission spectrum, we have undertaken to remeasure both of these quantities, using as nearly as possible the same experimental conditions in the two cases.

For this purpose we have employed a Coolidge X-ray tube with a rhodium target, the current through it coming from a high potential storage battery. In most of the experiments we held the voltage applied to the tube constant at 37750 volts by means of a variable resistance in series with the tube, and corrected for unavoidable variations from this value. A current of 2 milliampères passed through the tube. The X-rays were analyzed by means of an X-rays spectrometer, the 100 planes of a crystal of calcite reflecting the rays. The formula

$$\lambda = 6.056 \times 10^{-8} \sin \theta$$

gives the wave-length in terms of the grazing angle θ.

[1] Abstract of a paper presented at the New York meeting of the American Physical Society, April 27, 1918.

[2] The Critical Absorption of Some of the Elements for High Frequency X-rays, F. C. Blake and William Duane, Phys. Rev., Dec., 1917.

The X-rays passed through two narrow slits between the tube and the spectrometer, and the slit in front of the ionization chamber was broad enough to include the entire beam reflected from the crystal. Thus we eliminated errors coming from the penetration of the X-rays into the crystal, etc.[2]

In order to avoid actually determining the zero of the instrument we either measured the lines on each side of it, or else determined their positions in the spectra of both the first and second orders. The fact that the two sets of measurements agree shows that the planes of the crystal were not appreciably curved. The following table contains the data.

K-Series of Rhodium (45) $\lambda \times 10^8$ *cm.*

α_2.	α_1.	β.	γ.
.6164	.6122	.5451	.5342
.6163	.6121	.5453	.5343
.6161	.6120	.5454	.5342

In determining curves representing the ionization currents as a function of the angle θ, we took readings 15″ of arc apart. The slits were so narrow that the peaks corresponding to the two α-lines were completely separated from each other, although the difference between their wave-lengths is only 2/3 per cent. Under these conditions the ionization method furnishes an indicator so sensitive that the errors made are only those incurred in measuring an angle of 10° by means of two verniers. The verniers were supposed to read to 5″ of arc. The readings may be in error, however, by almost 10″, which means an accuracy of about 1/20 per cent., just about the variation in the table.

The critical absorption wave-length of rhodium determined last year was $\lambda_a = .5324 \times 10^{-8}$, *i. e.*, about 1/3 per cent. shorter than the wave-length of the γ-line in the above table. We have redetermined λ_a, using a tungsten target and an absorber consisting of a layer of rhodium salt, and find that, if we measure from the mid-points in the sharp drops on the two sides of the zero line, we get $\lambda_a = .5330 \times 10^{-8}$, and this differs from λ_γ by almost 1/4 per cent.

In order to obtain further evidence on the point we have made a series of experiments with the rhodium target tube with and without the rhodium salt absorber.

The curves obtained indicate that the rhodium has no appreciable selective absorption for its own α_1, α_2 and β lines and that the marked increase in absorption occurs in the peak corresponding to the γ line. Further the wave-length corresponding to the center of the peak is about 1/3 per cent. longer than that corresponding to the center of the absorption drop. This agrees with the above experiments.

It appears, therefore, that either the critical absorption wave-length is about 1/3 per cent. shorter than that of the γ-line, or else the wave-lengths do not

[2] See PHYS. REV., Dec., 1917, pp. 624–637.

correspond to the centers of the peak in the emission spectrum and of the drop in the absorption curve.

We have also made some experiments designed to detect any possible difference between the critical absorption wave-length of iodine and the wave-length corresponding to the sharp increase in ionization, when iodine is one of the elements in the gas in the ionization chamber. For this purpose we filled the ionization chamber with methyl-iodide, and used potassium iodide as an absorber. According to our measurements the critical absorption wave-length and the critical ionization wave-length are the same, namely $\lambda = .3737 \times 10^{-8}$ cm.

(This value agrees better with the data for neighboring elements than the value obtained last year for the critical ionization wave-length of iodine.)

THE RELATION BETWEEN THE GENERAL X-RADIATION AND THE ATOMIC NUMBER OF THE TARGET.[1]

BY WILLIAM DUANE AND TAKEO SHIMIZU.

IT is known that in general the intensity of the X-rays from a tube, other conditions being the same, increases with the atomic weight of the element used as a target. The literature, however, does not indicate conclusively whether the increase in intensity depends upon the atomic weight or the atomic number of the element. We know that the frequencies of the characteristic X-rays increase with the atomic numbers (not the atomic weights) of the elements, and it might be supposed from analogy that the intensity of the general X-radiation would also increase with the atomic number.

To decide this point we have investigated the general X-radiation from the four elements iron (26), cobalt (27), nickel (28) and copper (29). The atomic numbers of these elements appear in the brackets, and they are arranged in order of ascending atomic numbers. If they were arranged in order of ascending atomic weights the position of cobalt and nickel would be reversed, the atomic weight of cobalt being greater than that of nickel.

Sheets of these four elements each in the form of a quadrant of a circle were attached to the face of a circular copper disk, which was suspended in an X-ray tube so that it could be rotated about its axis. By means of a magnet outside of the tube acting on a piece of soft iron attached to the axle we could place any desired element in front of the cathode.

The current in an ionization chamber containing methyl iodide was taken as a measure of the intensity of radiation.

The table on following page contains the rates of increase in the potential of the ionization chamber's electrode in volts per second, when the different elements were used as targets. The first column contains the voltage V applied to the tube. A high potential storage battery produced the current which was maintained at 1 milliampere throughout the experiment.

[1] Abstract of a paper presented at the New York meeting of the American Physical Society, April 27, 1918.

Volts.	Ion.-Current (Volts per Sec.).			
	Cu (29).	Ni (28).	Co (27).	Fe (26).
19,140	.0124	.0120	.0114	.0110
21,430	.0386	.0375	.0344	.0336
24,120	.0544	.0532	.0502	.0492
27,300	.0812	.0790	.0762	.0732
30,110	.1088	.1061	.1021	.0981
32,400	.1327	.1295	.1251	.1210

The characteristic X-rays from these elements do not pass through the glass walls of the tube in perceptible quantities, unless the walls are very thin; so that in this experiment the radiation contained only general radiation up to frequencies given by the equation $Ve = h\nu$.

It appears that without exception the intensity of the X-radiation increases as the atomic number (not the atomic weight) of the target increases.

The intensity of radiation is approximately proportional to the atomic number, but the range of atomic numbers is too small to test the point accurately.

THE INFLUENCE OF AMALGAMATION VARIABLES UPON THE MERCURY CONTENT AND THE CRUSHING STRENGTH OF A DENTAL AMALGAM.[1]

BY ARTHUR W. GRAY AND PARIS T. CARLISLE, FOURTH.

THIS communication presents the results of some experiments undertaken for the purpose of determining how the mercury content and the crushing strength of a dental amalgam are affected by varying the mercury : alloy ratio and the trituration time.[2]

Cylinders of amalgam 10.04 mm. in diameter were prepared and tested as described by the authors at the Rochester meeting of the Physical Society.[3]

In one series of tests the mercury : alloy ratio was varied from 0.5 to 2.5, while the trituration time was maintained uniformly at 1.5 minutes. This varied the mix from a very stiff one to a very pasty one. When the cylinders were molded under a packing pressure of 141 kg. wt. per circular cm., both mercury content and crushing strength increased rapidly in the same general way to maximum values which remained constant as the mercury : alloy ratio was still further increased. Cylinders packed under 400 kg. showed the same general characteristics, but to a lesser degree; and the maxima were reached sooner. Increasing the packing pressure to 1,131 kg. produced cylinders of uniform mercury content and almost uniform strength.

[1] Abstract of a paper presented at the New York meeting of the American Physical Society, April 27, 1918.

[2] The *mercury: alloy ratio* refers to the masses of mercury and alloy that are triturated together to form an amalgam. In the process of molding this amalgam into cylinders for crushing tests some of the mercury, along with a small amount of alloy, is squeezed out by the packing pressure exerted through the piston of the mold. The per cent. of mercury in the finished cylinder is here designated as the *mercury content*.

[3] A. W. Gray and P. T. Carlisle, PHYS. REV., II., 154–156, 1918.

In a second series of tests the trituration time was varied from 1 to 8 minutes, while a constant mercury : alloy ratio of 1.40 was used. The curves representing the results show that, in general, more mercury is retained in a test cylinder by prolonging the trituration; but it is interesting to note that when the packing pressure is low, less mercury seems to be left in the cylinder by increasing the trituration time from one to two minutes. Apparently this is because the shorter trituration leaves many of the alloy granules so large that a low packing pressure is insufficient to squeeze out the free mercury from the spaces among the solid particles. The curves also show that for a given trituration time the mercury content changes almost inversely as the logarithm of the packing pressure.

Increasing the trituration time while the packing pressure is kept constant is accompanied by a progressive increase in strength until the latter reaches a maximum when the trituration is maintained for about six minutes. Prolonging the time beyond this brings about a very gradual falling off in strength on account of the partial setting of the amalgam during the mixing. The results also indicate that the logarithmic law connecting crushing strength and packing pressure, which the authors announced at the Pittsburgh meeting, is applicable for any given trituration time within the range investigated.

The experiments outlined above are of considerable practical importance in demonstrating that, contrary to the views now generally held both by dentists and by manufacturers of dental alloys, the strength of a tooth filling made from a high-grade dental amalgam is *not* lessened either by excess of mercury in making the mix or by long trituration within practicable limits; while on the other hand, a deficiency in mercury or too short a trituration time *does* result in a marked deficiency in strength. Moreover, the evidence undeniably contradicts the prevalent belief that the strength necessarily decreases with increase in the amount of mercury retained, and *because* of the mercury. Tests in addition to those reported here are all in harmony with the view that any procedure which makes for more intimate union between the mercury and the particles of alloy also makes for stronger tooth fillings. Thorough trituration with mortar and pestle, and sufficient mercury to make sure of saturating every granule of alloy, help in producing the desired intimate union.

Physical Research Laboratory,
The L. D. Caulk Company,
Milford, Delaware,
February 20, 1918.

Increase in Length of Life of Tribolium Confusum, due to X-Rays.[1]

By Wheeler P. Davey.

THE effects of X-rays upon living organisms, as reported by various investigators, fall into three distinct classes.

1. A stimulation.
2. A destructive effect which takes place only after a certain latent interval.

[1] Abstract of a paper presented at the New York meeting of the American Physical Society, April 27, 1918.

3. An instant destructive effect.

1. By analogy with the action of various drugs, it would be expected that the rays could be made to act in any one of these three ways at will by merely varying the size of the dose. In a previous paper,[1] the writer has shown that this is true for the last two of the three effects mentioned above. It is the purpose of the present paper to present evidence that this is true for the first effect also.

The organism used was the grain pest *Tribolium confusum*. The apparatus and technique were the same as in previous work. The present experiment is in two parts: (1) to find the effect of doses smaller than the minimum lethal dose, and (2) to find the effect of very small doses repeated daily. It has been shown possible to duplicate results, time after time, subject only to those general limitations which are inseparable from biological work.

1. The doses employed were 100, 200, 300 and 400 milliampere minutes at 25 centimeters distance and 50 kilovolts. In every case a group of beetles as large as the groups to be X-rayed, was kept as a control. In the experiment particularly described here there were approximately 850 individuals for each dose. The beetles were rather old, so that the controls were all dead on the fortieth day of the experiment. There were so few beetles still alive after the thirty-fifth day that the results of the last five days are not of the same order of accuracy as those of the first 35 days.

(*a*) *The group which was given* 100 MAM/25² at 50 kv. For the first 10 days this group had the same death rate as the controls. After the tenth day, the death rate was considerably less than that of the controls. This group and the control group were divided into two equal subgroups, and although it was found that the idiosyncrasy was such that the subgroups were not exactly alike, still after the tenth day the highest death rate of the X-rayed groups was lower than the lowest death rate of the controls. Out of each 100 individuals in the group, there were on the fiftieth day after raying,

3	more	beetles	alive	than	in	the	control	group,			
7	"	"	"	"	"	"	"	on	the	twentieth	day
13	"	"	"	"	"	"	"	"	"	twenty-fifth	"
10	"	"	"	"	"	"	"	"	"	thirtieth	"
5	"	"	"	"	"	"	"	"	"	thirty-fifth	"

(*b*) *The group which was given* 200 MAM/25² at 50 kv. During the first 17 days of the experiment, this group had a higher death rate than the controls. After the twentieth day the death rate was identical with that described under (*a*). When divided into two equal subgroups as described above, it was found that after the 22d day the highest death rate of the X-rayed group was lower than the lowest death rate of the control group.

(*c*) *The group which was given* 300 MAM/25² at 50 kv. During the first 29 days of the experiment, the death rate of this group was greater than that of

[1] PHYS. REV., June, 1917.

the controls. After the twenty-ninth day the death rate was less than that of the controls.

(*d*) The death rate of the group which was given 400 MAM/25² at 50 kv. was at all times greater than that of the controls.

2. Six groups were taken, of approximately 950 individuals each. These were known as groups *IV*, *IW*, *IX*, *IY*, *IZ* and *JA*.

Group *IV* was the "control"
IW was given $6\frac{1}{4}$ MAM/25² at 50 kv.—25 *MA* daily
IX was given $12\frac{1}{2}$ " " " " " " "
IY was given 25 " " " " " " "
IZ was given 50 " " " " " " "
JA was given 100 " " " " " " "

After 159 days the beetles were practically all dead. Death rates are shown in the following table:

Per cent. Dead.

Number of Days After Raying.	Group *IV* (Control).	Group *IW*.	Group *IX*.	Group *IY*.	Group *IZ*.	Group *JA*.
10	17	17	14	11	12	20
20	34	29	25	21	28	69
30	46	35	30	28	39	79
40	51	42	36	34	55	90
50	54	47	40	39	67	96
60	58	53	44	44	77	99
70	63	59	48	52	88	100
80	67	65	56	63	96	
90	74	74	69	79	98	
100	84	83	84	91	99	

By dividing each group into two equal subgroups, as described in (1) it was shown that, although the idiosyncrasy was great enough so that the curves of the subgroups could not be exactly superimposed, yet the lowest death rate among the controls (group *IV*) was higher than the highest death rate among the beetles of groups *IW*, *IX* and *IY*. It is interesting to note in this connection that the total dose received by these beetles was greatly in excess of that minimum dose which, when given all at once, would have caused premature death.

By plotting the data on probability paper, it was found that the curve for each group was composed of portions of three accurate probability curves, joined end to end. It is as though there were three causes of deaths, each represented by its own probability function. These three portions of the death rate curve will be termed *A*, *B*, and *C*. Portion *C* represents those beetles which lived the longest in their group. The following table gives the death rate per 100 in each group for *A*, *B* and *C*.

Group.	Daily Dose.	% which Died of "A."	% which Died of "B."	% which Died of "C."
IV.....	control	44	26	30
IW.....	$6\frac{1}{4}$	32	36	32
IX.....	$12\frac{1}{2}$	26	26	48
IY.....	25	21	35	44
IZ.....	50	23	61	16
JA.....	100	64	17	19

It is evident that the smallest daily dose (group *IW*) decreases the death rate of "*A*" and that those beetles which are kept from dying of "*A*" die of "*B*." Deaths from cause "*C*" are practically unaltered. A larger daily dose (group *IX*) causes almost half of those which would normally die of "*A*" to die of "*C*." A still larger daily dose (group *IY*) causes half of those which would have died of "*A*" to die of "*B*" and "*C*." A still larger daily dose (group *IZ*) acts much like the previous dose in causing about half of those which would have died of "*A*" to die of "*B*," but it differs from it in that some of those which would normally have died of "*C*" are prematurely killed. The largest daily dose employed (group *JA*) caused about a third of those which would have died of "*B*" and "*C*" to die of "*A*."

The following is an effort at an interpretation which does not involve too deeply questions of histology. Group *JA* shows that the lethal action of X-rays is tied up in some way with cause of death "*A*." It is well known that the lethal action of X-rays is more marked on cells in the process of division than on those in the resting state. Therefore, small daily doses (larger than a certain minimal value) can kill off those few cells which happen to be in a state of division at the time of raying. The deaths of these few cells stimulate the production of more to take their places. Therefore, small daily doses, instead of increasing the death rate from cause "*A*," actually *decrease* it by stimulating the processes of repair. The whole individual beetle, therefore, has a smaller chance of dying from "*A*" and is compelled to die of either "*B*" or "*C*." When the daily dose is increased to such a value that the daily destruction of cells is equal to or greater than the production of new cells, premature death results from causes "*B*" or "*A*" (see groups *IZ* and *JA*, above). At any rate, irrespective of what the cause of death of the *Tribolium confusum* may be, and irrespective of what may be the method by which X-rays produce their effect, we may regard it as well established that it is possible for X-rays to cause in these beetles an increase in length of life.

SUMMARY.

Using the same kind of organism throughout the whole experiment, it has been shown that by merely varying the size of the dose, a purely physical agent (X-ray) may be made to produce at will, (1) a stimulation, (2) a destructive effect which occurs only after a latent interval, or (3) an instant destructive effect.

RESEARCH LABORATORY,
GENERAL ELECTRIC CO., SCHENECTADY.

THE SPECTRAL PHOTOELECTRIC SENSITIVITY OF MOLYBDENITE.

BY W. W. COBLENTZ, M. B. LONG AND H. KAHLER.

CONTINUING this investigation,[1] we have found that (1) samples of molybdenite, obtained from various localities, differ greatly in sensitivity; (2) there are maxima of sensitivity at 0.6μ, 0.75μ, 1.02μ, and 1.8μ; (3) there is no simple law governing the variation in the photoelectric response with variation in intensity of the radiation stimulus; (4) the increase in photoelectric current with increase in intensity of the incident radiation is greatest in the infra-red. It is greatest for low intensities and it is greatest on the long wave-length side of the maximum; (5) the photoelectric sensitivity increases with decrease in temperature. At 70° C. the bands at 1.02μ and 1.8μ have practically disappeared.

WASHINGTON, D. C.,
April 6, 1918.

THE INFLUENCE OF AMPLITUDE AND OF ELECTOMAGNETIC DRIVING ON THE FREQUENCY OF TUNING FORKS.[2]

BY DAYTON C. MILLER.

TUNING forks are commonly considered as having a frequency of one standard value. Only in rare instances is attention given to the influence of conditions of operation and usually notice is taken of the temperature effect only. Three other causes produce variations which may be as great as that due to temperature: (*a*) the resonance box, its presence or absence, and its tuning, whether sharp or flat of the fork; (*b*) the amplitude of the motion of the prong of the fork; (*c*) the effect of electromagnetic maintenance of vibration.

The Koenig Clock-Fork has been used in an extended investigation of the

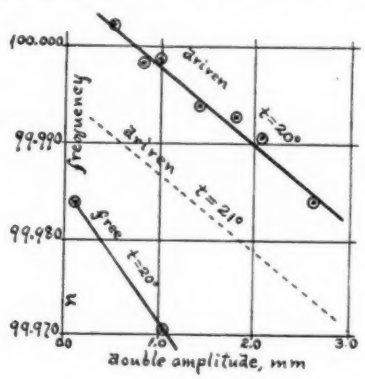


Fig. 1.

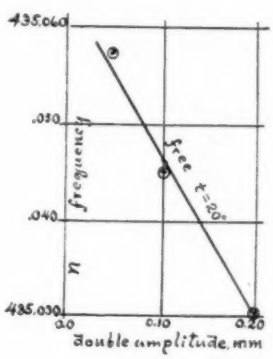


Fig. 2.

frequency of tuning forks, and a report is made of the effects of amplitude and of electromagnetic driving. Figs. 1 and 2 show results for two forks of a kind

[1] Reported upon at the Pittsburgh meeting, Dec. 28, 1917.

[2] Abstract of a paper presented at the New York meeting of the American Physical Society, April 27, 1918.

in common use; the first, having a frequency of 100, is such as would be used in chronographic work, and the other, having a frequency of 435, is in common use in connection with musical scales.

Fig. 1 shows that the fork, at 20° C., and electromagnetically driven, when vibrating through 0.75 mm. double amplitude, has a frequency of 100.000. When the fork is struck with a felt hammer and allowed to vibrate freely and when the amplitude has naturally decreased from a greater initial value to that previously mentioned, 0.75 mm., the frequency is 99.975. Thus the electromagnetic driving increases the frequency in this instance about one part in 4,000. When being driven electromagnetically, if the width of swing (double amplitude) is increased from 0.75 mm. to 2.0 mm. the frequency falls to 99.990, that is, it is decreased by one part in 10,000.

Fig. 2 shows the effect of the amplitude on the frequency of a fork of 435 vibrations per second; for a double amplitude of 0.05 mm., the frequency is 435.055; for double amplitude of 0.20 mm. the frequency is 435.030.

The diagrams show that change in pitch is a linear function of the amplitude for each fork, and a further study indicates that for various forks, it is a function of the square of the frequency. The following equation expresses the results in a convenient form for calculating the change in frequency, Δn, in terms of the arbitrary coefficient k, the frequency n, and the double amplitude (width of swing of end of prong) $2a$:

$$\Delta n = k.n^2.2a.$$

The numerical value of the coefficient which satisfies the measures so far made is $k = 8.4 \times 10^{-6}$.

The fact that the variation in the frequency with a change in the amplitude is a function of the square of the frequency suggests that variation in amplitude causes a change in the elasticity of the material of the fork, but further consideration shows that the probable change in elasticity would affect the frequency in a direction contrary to that observed. Therefore it seems more probable that the variation in amplitude changes the effective length of the prong. If this is true the numerical value of k would be dependent upon the shape of the yoke of the fork. All the forks so far tested are of the shape commonly known as that of Koenig. Further investigation will be made for discussion in the full report.

THE LAW OF SYMMETRY OF THE VISIBILITY FUNCTION.[1]

BY IRWIN G. PRIEST.

IF the relative visibility of radiant power is plotted as ordinate against wavelength as abscissa, a striking characteristic of the resulting curve is its rough approximation to symmetry about the maximum ordinate.[2] Troland indeed

[1] Abstract of a paper presented at the New York meeting of the American Physical Society, April 27, 1918.

[2] See determinations of visibility by Ives, Nutting, Coblentz and Emerson. Phil. Mag., Dec., 1912, p. 853. Trans. I. E. S., 9, 633 (1914). B. S. Sci. Paper *303*.

has particularly drawn attention to this fact and used it as a basis for deductions in regard to the nature of the response of the retina.[1] He has, moreover,

Wave Lengths, Millimicrons.	Frequency $\frac{\text{vibrations}}{\text{sec.}} \times 10^{12}$.	Relative Retinal Visibility from Original Fig. 14 B. S. Sci. Pap. 303.	$e^{-0.0002664(f-541)^2}$.
420	714	0.028	
430	698	033	
440	682	041	
450	667	055	
460	652	073	
469	640	104	0.074
470	638	107	
476	630	138	121
480	625	161	
484	620	192	190
490	612	248	
492	610	270	281
500	600	385	
508	590	545	527
510	588	585	
520	577	762	
526	570	849	799
530	566	892	
540	556	962	
545	550	985	979
550	546	996	
560	536	998	
566	530	979	968
570	526	959	
577	520	915	889
580	517	890	
590	508	785	
600	500	669	639
610	492	538	
612	490	510	500
620	484	409	
625	480	350	371
630	476	290	
638	470	203	261
640	468	184	
650	462	115	
652	460	102	174
660	454	067	
670	448	037	
680	441	020	
682	440	018	066
690	435	010	
700	428	005	
710	422	003	
720	417	001	

[1] Trans. I. E. S. *11*, 956 (1916), and Jour. Op. Soc. of Am., *1*, 14 (1917).

pointed out that, for this purpose, the experimentally determined visibility should be corrected for the selective absorption of the ocular media so as to obtain the visibility *to the retina;* and has stated that Nutting's data reduced in this way gives a very symmetrical curve. Coblentz and Emerson have reduced their own data in the same way, applying the same correction as used by Troland[1] and state that the resulting curve has a very symmetrical form.[2] The degree of symmetry is not easily inferred from their published figure. Dr. Coblentz has kindly given me the original from which this figure (Fig. 14, B. S. Sci. Paper 303) was reproduced. Values read from this original figure are shown in table on page 499.

It appears that while this curve is more nearly symmetrical than the uncorrected curve, the symmetry is still far from perfect, as is shown in the accompanying figure where these same data have been replotted in a way to exhibit the departure of the curve from perfect symmetry.

It would seem *a priori* more likely that a simple relation should exist between frequency and visibility than between wave-length and visibility. That this assumption is justified will be shown below. It will be shown that for all values of visibility greater than 15 per cent. of the maximum, the retinal visibility curve with respect to frequency is much more symmetrical than the one with respect to wave-length.

The corrected data of Coblentz and Emerson mentioned above have been plotted against frequency in the accompanying figure. From this plot the following conclusions are drawn:

1. *For all values of visibility greater than 20 per cent. of the maximum, the curve of average retinal photopic visibility plotted against frequency is symmetrical about the ordinate of maximum visibility at 541 vibrations per trillionth of one second.*

2. In more general terms, we may say: *The average photopic visibility-frequency curve of the retina is perfectly symmetrical throughout the spectral region in which it is accurately known and not affected by extraneous phenomena.* (Wave-length = 490 to 690 millimicrons. Frequency = 612 to 435 vibrations per trillionth of one second.) There may be some ground for questioning this latter conclusion, but it is supported by the following considerations:

(*a*) The correction to be applied for the selective absorption of the eye depends upon the age of the subject and is doubtless very uncertain for frequencies greater than six hundred trillions per second. (Wave-length = 500 millimicrons.)

(*b*) The symmetry of the curve is literally perfect throughout the region in which Coblentz and Emerson claim high accuracy for their data based on a large number of observers.[3]

(*c*) The rise of the experimental curve above the symmetrical curve in the blue and violet may be due in part at least to the fluorescence of the retina or ocular media which logically should be considered apart from true visibility.

[1] Trans. I. E. S., *11*, p. 956, Fig. 2.

[2] B. S. Sci., *303*, p. 222, and Fig. 14, p. 216.

[3] B. S. Sci., *303*, p. 221.

(*d*) The determinations of visibility at the ends of the visible spectrum are probably affected by unavoidable scotopic conditions.

3. To an approximation which is quite close relative to the differences between individuals, the average retinal visibility shown by the solid line in

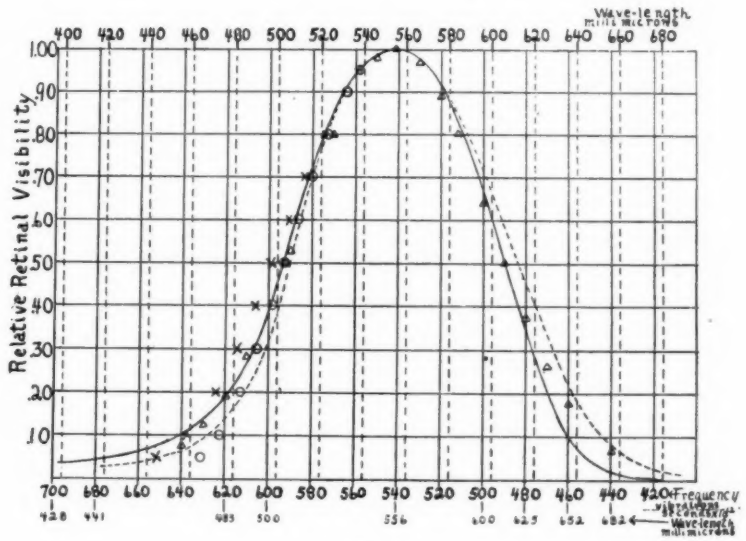


Fig. 1.

RELATIVE VISIBILITY OF RADIANT POWER.

Data of Coblentz and Emerson corrected for selective absorption of ocular media (Fig. 14, B. S. Sci. Paper 303).

——— Visibility plotted against frequency scale at bottom of figure.

----- Visibility plotted against wave-length scale at top of figure.

ooooo Points symmetrical with right-hand part of visibility-frequency curve.

xxxxx Points symmetrical with right-hand part of visibility-wave-length curve.

} About ordinate axis at frequency = 541,000,000,000,000 per second. (Wave-length. =555 millimicrons.)

ΔΔΔΔ Points determined by equation

$$V = e^{-0.0002664(f-541)^2}.$$

Note: The wave-length scale at top and the frequency scale at bottom have been placed to make the maximum ordinates of the visibility curves coincide, but there is no other assigned relation between these two scales. The wave-length scale at the bottom gives merely wave-length equivalents of frequencies on the frequency scale.

the accompanying figure is represented by the one term exponential formula ("probability curve")

$$V = e^{-0.0002664(f-541)^2},$$

where f is frequency in vibrations per trillionth of one second and V is the ratio of visibility at frequency f to the maximum visibility at frequency = 541.

Computations by this formula are compared with the above data in the accompanying table and figure.

It may be noted that through the brighter part of the spectrum the symmetry of the curve is slightly more accurate than is the representation of the curve by the probability function.

A different value of the exponential constant might be chosen which would give a smaller average departure for a greater wave-length range; and a more complex equation could of course be formulated which would better represent the whole curve including the ends of the spectrum; but in the present state of experimental knowledge,[1] it is hardly worth while to make these more precise adjustments for the retinal curve. Such equations representing *effective* visibility, are already available for practical purposes.[2]

The essential purpose of the present paper has been accomplished in exhibiting and quantitatively formulating the striking symmetry of the *retinal visibility-frequency* curve for the higher luminosities, on the basis of the best data now available. It is hoped that the simple relations herein established may be useful in the development of the theory of the physico-physiological process of light perception.

NATIONAL BUREAU OF STANDARDS,
April 5, 1918.

A PRECISION METHOD FOR PRODUCING ARTIFICIAL DAYLIGHT.[3]

BY IRWIN G. PRIEST.

LIGHT having a spectral distribution of energy closely approximating that of daylight (black body at 5,000° abs., sun at the earth's surface or sun outside the earth's atmosphere) may be produced by passing the light from an artificial source (acetylene flame, vacuum tungsten lamp or gas-filled tungsten lamp) through two nicol prisms with a crystalline quartz plate between them, the path of the light being parallel to the optic axis of the quartz, and the thickness of the quartz as well as the angle between the principal planes of the nicols being properly chosen. If three nicols are placed in series in the beam, one quartz plate being placed between the first and second nicols and another quartz plate between the second and third nicols, the approximation to a desired spectral energy distribution may be made still closer.

Nicols are designated 1, 2, 3, in order from the source of light.

ϕ = angle of rotation of nicol No. 2, measured from its position for extinction with nicol No. 1 (quartz removed), the rotation being in the same direction as the rotation of the plane of polarization by the quartz plate.

ϕ' = angle of rotation of nicol No. 3, measured from its position for extinction with nicol No. 2 (same convention as above).

L = thickness of first quartz plate (near source).

[1] Coblentz and Emerson, B. S. Sci. Paper *303*, p. 221.

[2] Kingsbury, PHYS. REV., 7, p. 161 (1916). Coblentz and Emerson, B. S. Sci. Paper *303*, p. 223.

[3] Abstract of a paper presented (by title) at the New York meeting of the American Physical Society, April 27, 1918. (Submitted for March 2 meeting which was cancelled.)

L' = thickness of second quartz plate.
α = specific rotation of quartz $\left(\frac{\text{degrees}}{\text{mm.}}\right)$.
E_1 = relative energy of actual source used.
E_2 = relative energy after light has passed through quartz-nicol system.

} Functions of wave-length.

Relative energy for any wave-length is computed by:

$$E_2 = E_1 \operatorname{Sin}^2 (L\alpha - \phi),$$

if a simple system of two nicols and one plate is used,

or $$E_2 = E_1 \operatorname{Sin}^2 (L\alpha - \phi) \operatorname{Sin}^2 (L'\alpha - \phi')$$

if a compound system of three nicols and two plates is used.

The rotatory dispersion of quartz has been previously used by others in "chromoscopes," etc. The novelty of the present communication consists solely in showing how it may be used in producing "artificial daylight"; and in presenting precise specifications for producing the results.

Constants of apparatus to produce certain particular spectral energy distributions have been computed as follows:

1. *Black Body at* 5000° *abs.* (*Planck Equation*).

(*a*) Simple system of two nicols and one quartz plate.

Relative Energy.

Wave Length.	Black Body.	Above System.
410 $\mu\mu$	74	69
480	92	86
590	100	100
680	94	85
720	90	73

Source: Acetylene flame or vacuum tungsten lamp at 1.22 w. p. m. h. c.

L = 1.00 mm. ϕ = 5.5 degrees.

The resultant spectral energy curve is smooth through the visible with a flat maximum at $\lambda = 570\mu\mu$.

(*b*) Compound system of three nicols and two quartz plates.

Source: Acetylene flame or vacuum tungsten lamp at 1.22 w. p. m. h. c.

L = 1.00 mm. ϕ = 2.0 degrees. L' = 0.5 mm. ϕ' = 145 degrees.

The resultant energy distribution through the visible ($420\mu\mu$ to $720\mu\mu$) matches the theoretical black body distribution closely, the maximum departure being about 4 per cent.

2. *Sun at the Earth's Surface.*

Simple system of two nicols and one quartz plate.

Source: Gas-filled tungsten lamp at 15.6 l. p. w.

L = 0.50 mm. ϕ = Zero (crossed nicols).

See accompanying figure.

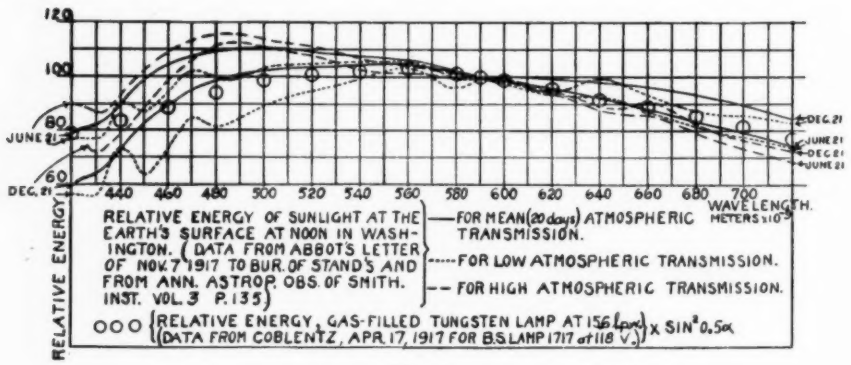

120
100
80
60
JUNE 21
DEC. 21
440 460 480 500 520 540 560 580 600 620 640 660 680 700
WAVE LENGTH. METERS x10⁻⁷
RELATIVE ENERGY
RELATIVE ENERGY OF SUNLIGHT AT THE EARTH'S SURFACE AT NOON IN WASHINGTON. (DATA FROM ABBOTS LETTER OF NOV. 7 1917 TO BUR. OF STAND'S AND FROM ANN. ASTROP. OBS. OF SMITH. INST. VOL. 3 P. 135)
—FOR MEAN (20 days) ATMOSPHERIC TRANSMISSION.
-----FOR LOW ATMOSPHERIC TRANSMISSION.
– – FOR HIGH ATMOSPHERIC TRANSMISSION.
000 {RELATIVE ENERGY, GAS-FILLED TUNGSTEN LAMP AT 156 l.p.w. (DATA FROM COBLENTZ, APR. 17, 1917 FOR B.S. LAMP 1717 at 118 V.)} x SIN⁴ 0.5α

Fig. 1.

Showing the reproduction of sunlight by passing the light from a gas-filled tungsten lamp through a quartz plate 0.500 thick between crossed nicol's, the path of the light being parallel to the optic ax's of the quartz.

3. *Sun Outside Atmosphere.*

Simple system of two nicols and one quartz plate.

Source: Gas-filled tungsten lamp at 22 l. p. w.

$L = 0.50$ mm. $\phi = 1.0$ degree.

The spectral energy of the light by this system agrees with the spectral energy of the sun outside the earth's atmosphere (Abbot) to within about 2 per cent. between wave-lengths $520\mu\mu$ and $690\mu\mu$. The maximum difference in the visible occurs at $470\mu\mu$ and is about 13 per cent.

This method, of course, is not adapted to illuminating large surfaces and so is not a commercial competitor with the blue glass method or other "artificial daylights." It is, however, very well adapted to use with instruments (photometers microscopes, etc.) where the quartz-nicol system may be inserted between the eyepiece of the instrument and the observer's eye.

The chief advantages of this method over the blue glass method are:

1. A much more accurate reproduction of the desired spectral energy distribution. The distributions obtained by the use of blue glass (*e. g.*, Luckiesh's, "Trutint" or Corning, "Daylite") are always distorted from the desired distribution by a sharp maximum at $\lambda = 570\mu\mu$ as well as by a rise in the red for λ greater than 660.

2. Certain reproducibility and definiteness of specifications.

3. Adjustability. By varying ϕ the distribution may be slowly changed by known amounts.

A more detailed treatment of this subject will probably appear later in the Bulletin of the Bureau of Standards.

The author expresses his appreciation of the assistance of Messrs. H. J. McNicholas, J. T. Filgate and H. E. Cole in carrying through the very extensive computations by which the above results were obtained and checked.

NATIONAL BUREAU OF STANDARDS,
February 15, 1918.

TRANSPARENCY OF CERTAIN CARBON COMPOUNDS TO WAVES OF GREAT LENGTH.[1]

BY H. P. HOLLNAGEL.

THE high transparency of quartz to residual rays of rock salt ($\lambda = 52\ \mu$) is well known. A search has been made for other substances of high transmission of energy. It has been found that benzene is two and one half times more transparent, carbon tetrachloride eight times and carbon bisulphide ten times more transparent to radiation of this length ($\lambda = 52\ \mu$) than is quartz. It seems evident that studies of transmission may throw some light on molecular structure. A number of substances, among which are ethyl alcohol, ethyl ether, methyl alcohol, glacial acetic acid, acetyl chloride, glycerine, show practically total absorption of energy of this wave-length in a thickness of 1 mm.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
CAMBRIDGE, MASS.

SOME PRELIMINARY RESULTS IN A DETERMINATION OF THE MAXIMUM EMISSION VELOCITY OF THE PHOTOELECTRONS FROM METALS AT X-RAY FREQUENCIES.[1]

BY KANG-FUH HU.

IT has been known for some time that when X-rays are allowed to fall on a metallic plate, a stream of electrons of great velocities is emitted. Early experiments brought out the existence of a close relationship between their maximum velocity and the frequency of the incident rays, together with the independence of this velocity on the intensity. The known approximate equality of this maximum velocity to the critical minimum velocity of electrons in the tube generating the parent X-rays, when coupled with the known quantum production of X-ray, suggests strongly, that the same law might apply also to this inverse process of photoemission in agreement with other evidences in this field. But quantitative results are lacking. Whiddington's results (and others using the same method) do not show numerical agreement with the quantum values. Robinson and Rawlinson, using a different method, obtained some interesting results. But they are hard to interpret beyond establishing the fact that in some way both the nature of the source and that of the radiator are involved. The present work is a preliminary account of an attempt to get some qualitative and quantitative data regarding this important question.

The method used in obtaining the main results was similar to that employed by several other experimenters. Briefly it is this. A plate (radiator) is placed in a uniform magnetic field and exposed to X-rays. The paths of electrons, deflected into circles by the field, are intercepted by a photographic plate.

[1] Abstract of a paper presented at the New York meeting of the American Physical Society, April 27, 1918.

The image, the source and a slit across the path of the electron together determine the radii involved in the calculation of velocities.

With a constant applied potential on a tungsten Coolidge tube and a constant magnetic field, silver and lead plates, and a silver foil backed or not backed by a lead plate were successively tried as radiators. A continuous spectrum was obtained, the limiting edge of which was identical in every case. With the silver radiators, two strong lines were found in addition. Their external edges were taken as the true maximum velocities of the electrons involved in the emission, and the measurements were compared with the values calculated from the known characteristic X-ray wave-lengths (from Siegbahn). They are readily shown to correspond to the K_β and K_α doublets of silver. The faint limiting edge of the continuous spectrum was found on measurement to have the same relative agreement with that calculated from the applied voltage on the tube by $\frac{1}{2}\, mv^2 = h\nu = Ve$. The numerical agreement or disagreement with the quantum value is about 5 or 6% (calculated on velocity), the experimental being always the smaller of the two, but the exact figure may need further revision. A lead plate gave no L lines under the above conditions.

The same relative agreement among the K lines and the limit of the continuous spectrum is interesting, as the line and continuous spectra have distinct origins. In order to further confirm this point, a tin foil was placed in front of the silver plate. Its thickness was about .025 mm., enough to stop the electrons of maximum velocity twice over. There was consequently no chance for electrons starting from the Ag plate to get through. The spectrum obtained showed four lines, two of which nearly coincided. Two of the lines of small velocities were identical with the Ag lines previously obtained, while the other two new ones were found to be Sn K_β and K_α, the latter coinciding with the K_β of Ag, as is evident from the X-ray data. But here again, all four sets of electrons started from the tin, though two of these were directly excited by the primary X-rays in the body of Sn itself and the other two only indirectly excited by the secondary Ag X-radiations produced. Thus the two apparently distinct processes involved (which we may call "characteristic" and "independent" emission respectively, in analogy with the X-rays) gave the same result, a point not to be expected, if we consider the reverse process of X-ray emission. This is evidently due to the important part that the secondary electrons must be playing in the emission of the characteristic X-radiations.

Experiments are still in progress to see whether there is a characteristic L electronic emission in connection with the K and to see if there is a real difference from the simple equation $\frac{1}{2}\, inv^2 = h\nu$, such as would be suggested by the term "$-p$" in Einstein's form of the equation.

In order to define ν still more accurately, attempts were made to use a rhodium tube. The point was to obtain the line spectrum of rhodium, the source on the same plate as that due to the radiator. Not only this would be the most direct evidence for the point, but this would enable us to study the ques-

tion whether the characteristic electrons are separately excitable or whether they must be excited together under certain critical conditions, as suggested by research in X-rays. They are unsuccessful chiefly on account of the insufficient intensity.

Qualitative results have also been obtained with the method of retarding potential, so universally used in the regions of lower frequencies, but never yet tried with the high frequencies, evidently owing to the extreme difficulties in operation. Unfortunately the work had to be abandoned, while fairly on way to quantitative measurements, owing to an accident to the bulb which the writer has not yet been able to replace satisfactorily. A simple electroscope, containing the radiator as a part, was mounted inside a vacuum bulb and carefully insulated. X-rays were allowed to fall on the plate. Of the qualitative results, it is perhaps interesting to note that an accumulation of + charge amounting to about 300 volts (capacity = 3 to 4 cm.) was observable in the course of the first 30 minutes, with a Ag plate and a silvered bulb, both initially uncharged, indicating a current of some magnitude. No accumulation time was observable. The electroscope would go up or down according as it was previously charged to a + or − potential but ultimately charged up positively in all cases. The true effect was however only observable with the highest attainable vacuum and after the electrons from the ends of the glass tube had been removed by a magnetic field, else the leakage due to these electrons and the attending ionization from all sources would be at least twice as great as the effect sought, showing however still the proper polarity in emission, within certain limits of the conditions. The vacuum was pumped by the charcoal method, it was so high that the absorption power of charcoal at ordinary temperature was not distinguishable from that with the liquid air. In one case, even under a vacuum somewhat inferior to the present one, a Pt wire electroscope was charged to 15,000 volts and left standing for over a week without being perceptibly discharged.

The effect was however always in the reverse direction, when the plate was made of Al instead of Ag. It seems that there is a tremendous difference in the emitting power among the various chemical elements, so that the scattered X-rays are able to excite more electrons from the Ag wall than the primary ray can from the Al plate itself. This might have had a bearing on many previous observations, where the conditions were not so definitely known.

With a retarding potential of slightly under 20,000 volts, the proper effect was observed with Ag and W plates, though not measured. The potential on the X-ray tube was about 40,000 volts. The quantitative investigation of the maximum velocity and the velocity distribution were interrupted prematurely.

Perhaps a combination of these two methods would be desirable, as the photographic method is very insensitive (at least 25 hrs. with an input of 200 watts into a tungstun tube) and the method of retarding potential, though feasible, is at best, a risky proposition.

JEFFERSON PHYSICAL LABORATORY,
HARVARD UNIVERSITY.

ERRATUM.

Vol. XI., May, 1918, page 363, article by T. Peczalski, entitled "Effect of Hydrogen on the Electrical Resistivity of Carbon"; in Figs. 2, 4 and 5, the scale values and meaning of coördinates were omitted. These figures are here reproduced with the coördinates and scale values correctly indicated.

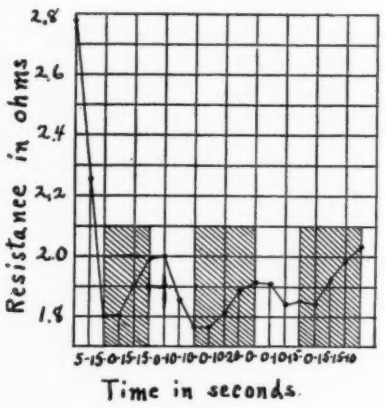


Fig. 2.

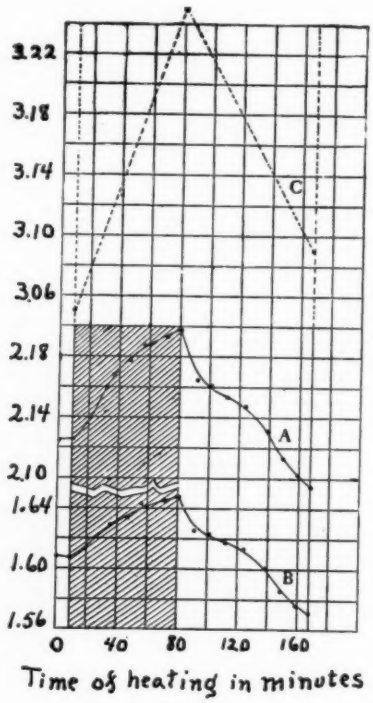


Fig. 5.

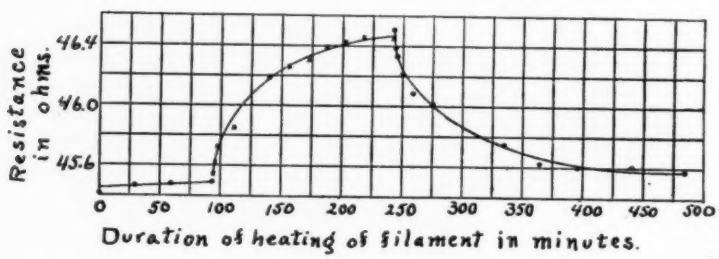


Fig. 4.

Index to Volume XI., Series II.

A.

Absorption, On the Unpolarized Fluorescence and, of Four Double Chlorides of Uranyl, *Edward L. Nichols* and *H. L. Howes*, 285.

Absorption Bands, on Certain, in the Spectra of the Uranyl Salts, *H. L. Howes*, 66.

Absorption Bands, On Certain, in the Spectra of the Uranyl Salts, *H. L. Howes*, 143.

Achromatization, Complete, of a Two-Piece Lens, *G. W. Moffitt*, 144.

Air, Mobility of Ions in, Hydrogen, and Nitrogen, *Kia-Lok Yen*, 248.

Air-Damped Vibrating System, The, Theoretical Calibration of the Condenser Transmitter, *I. B. Crandall*, 449.

Alter, Dinsmore, Variation of Velocity of Waves due to Motion of the Source, 481.

Alternating Current, Rectification of, by the Corona, *J. W. Davis*, 243.

Amalgamation Variables, The Influence of, upon the Mercury Content and the Crushing Strength of a Dental Amalgam, *Arthur W. Gray* and *Paris T. Carlisle, Fourth*, 492.

American Physical Society:
Abstracts, 132, 241, 326, 479.
Minutes, 130, 477.

Artificial Daylight, A Precision Method for Producing, *Irwin G. Priest*, 502.

Assmann Aspiration Psychrometer, Comparative Accuracy of Whirled Psychrometer, Porous Cup Atmometers, Hair Hygrographs, Piche Evaporimeter Saturation Deficit Recorder, Open Water Surface Evaporimeter, and Dry and Wet Bulb Thermometers, *Alexander McAdie*, 152.

Atomic Number, Electronic Frequency, and, *Paul D. Foote*, 487.

Audion Characteristic Curves, The Effect Produced upon, by Various Kinds of Signals (Buzzer, Electron Relay and 60-Cycle A. C.), *A. D. Cole*, 331.

Audions, Characteristic Curves of Various Types of, *A. D. Cole*, 330.

Aurora Model, Photograph of an, *C. C. Trowbridge*, 482.

Auroral Streamers, On the Observation of the Apparent Focus of, *C. C. Trowbridge*, 483.

B.

Benade, J. M., Elasticity of Impact of Electrons with Gas Molecules, 184.

Benade, J. M., The Theory of Ionization by Collision. IV. Cases of Elastic and Partially Elastic Impact, 234.

Bichowsky, F. Russell v., The Necessary Physical Assumptions Underlying a Proof of the Planck Radiation Law, 58.

Birge, Raymond T., The Mathematical Structure of Band Series, II., 136.

Blanchard, Julian, The Brightness Sensibility of the Retina, 81.

Bohr's Atom, Zeeman's Effect and the Magnetic Properties of the Elements, *Jakob Kunz*, 153.

Boron Conductors, The Breakdown Effort in, *F. W. Lyle*, 253.

Breakdown Effort, The, in Boron Conductors, F. W. Lyle, 253.

Bridgman, P. W., On Equilibrium under Non-Hydrostatic Stress, 180.

Brown, Thomas B., Kathodo-Fluorescence of Crystals, 39.

Buzzer, The Effect Produced upon Audion Characteristic Curves by Various Kinds of Signals (Electron Relay and 60-Cycle A. C.), *A. D. Cole*, 331.

C.

Calcite, Note on a Phosporescent, *H. L. Howes*, 327.

Calcite, Note on the Grating Space of, and the X-Ray Spectrum of Gallium, *Arthur H. Compton*, 430.

Calcite, The Photo-Luminescence and Katho-Luminescence of, *E. L. Nichols, H. L. Howes* and *D. T. Wilber*, 485.

Calorimetric Work, Thermo-couples for Student Use in, *Ralph S. Minor*, 479.

Carbon, Effect of Hydrogen on the Electrical Resistivity of, *T. Peczalski*, 363.

Carbon Compounds, Transparency of Certain, to Waves of Great Length, *H. P. Hollnagel*, 505.

Carlisle, 4th, Paris T., The Influence of Temperature Upon the Crushing Strength of a Dental Amalgam, 154.

Carlisle, Fourth, Paris T., The Influence of Amalgamation Variables upon the Mercury Content and the Crushing Strength of a Dental Amalgam, 492.

Cathode Ray Excitation, A Preliminary

Study of the Luminescence of the Uranyl Salts under, *Frances G. Wick* and *Louise S. McDowell*, 421.
Coblentz, W. W., The Spectral Photoelectric Sensibility of Molybdenite, 497.
Coefficient of Expansion, Young's Modulus of Drawn Tungsten and its Variation with Change of Temperature, including a Determination of the, *H. L. Dodge*, 311.
Cole, A. D., Characteristic Curves of Various Types of Audions, 330.
Cole, A. D., The Effect Produced upon Audion Characteristic Curves by Various Kinds of Signals (Buzzer, Electron Relay and 60-Cycle A. C.), 331.
Collision, The Theory of Ionization by, IV. Cases of Elastic and Partially Elastic Impact, *K. T. Compton* and *J. M. Benade*, 234.
Collision, A Correction in the Theory of Ionization by, *Jakob Kunz*, 246.
Compton, Arthur H., The Nature of the Ultimate Magnetic Particle, 132.
Compton, Arthur H., The Size and Shape of the Electron, 330.
Compton, Arthur H. Compton, Note on the Grating Space of Calcite and the X-Ray Spectrum of Gallium, 430.
Compton, K. T., Elasticity of Impact of Electrons with Gas Molecules, 184.
Compton, K. T., The Theory of Ionization by Collision. IV. Cases of Elastic and Partially Elastic Impact, 234.
Condenser Transmitter, The Air-Damped Vibrating System, Theoretical Calibration of the, I. B. Crandall, 449.
Crandall, I. B., The Air-Damped Vibrating System, Theoretical Calibration of the Condenser Transmitter, 449.
Crystals, Kathodo-Fluorescence of, *Thomas B. Brown*, 39.

D.

D Lines, The Ratio of the Intensities of the, of Sodium, *Vivian Voss*, 21.
Davey, Wheeler P., Emulsions: (*a*) A New Method for Making Emulsions. (*b*) Properties of Emulsions, 138.
Davey, Wheeler P., Increase in Length of Life of Tribolium Confusum, 493.
Davis, Bergen, Characteristic X-Ray Emission as a Function of the Applied Voltage, 433.
Davis, J. W., Rectification of Alternating Current by the Corona, 243.
Dempster, A. J., A New Method of Positive Ray Analysis, 316.
Dental Amalgam, The Influence of Temperature upon the Crushing Strength of a, *Arthur W. Gray* and *Paris T. Carlisle, Fourth*, 154.
Dental Amalgam, The Influence of Amalgamation Variables upon the Mercury Content and the Crushing Strength of a, *Arthur W. Gray* and *Paris T. Carlisle*, 492.
Derieux, John B., Photoelectric Effects on Mercury Droplets, 276.
Dershem, Elmer, A Mono-Wave-Length X-Ray Concentrator, 244.
Dershem, Elmer, Wave-Lengths of the Tungsten X-Ray Spectrum, 244.
Dershem, Elmer, Wave-Lengths of the Tungsten X-Ray Spectrum, 461.
Derieux, John B., The Use of Mercury Droplets in Millikan's Experiment, 203.
Dodd, L. E., Further Verification of Knudsen's Equations for Resistance to Molecular Flow, 242.
Dodge, H. L., Young's Modulus of Drawn Tungsten and its Variation with Change of Temperature, including a Determination of the Coefficient of Expansion, 311.
Doubt, Thomas E., The Determination of Organic Compounds by an Optical Method, 249.
Duane, William, On the Critical Absorption and Characteristic Emission X-Ray Frequencies, 489.
Duane, William, On the Relation between the K X-Ray Series and the Atomic Numbers of the Chemical Elements, 488.
Duane, William, The Relation between the General X-Radiation and the Atomic Number of the Target, 491.

E.

Elasticity of Impact of Electrons with Gas Molecules, *J. M. Benade* and *K. T. Compton*, 184.
Electrical Resistivity, Effect of Hydrogen on the, of Carbon, *T. Peczalski*, 363, 508.
Electromagnetic Driving, The Influence of Amplitude of, on the Frequency of Tuning Forks, *Dayton C. Miller*, 497.
Electron, The Size and Shape of the, *Arthur H. Compton*, 330.
Electrons, Elasticity of Impact of, with Gas Molecules, *J. M. Benade* and *K. T. Compton*, 184.
Electrons, The Resonance and Ionization Potentials for, in Thallium Vapor. *Paul D. Foote* and *Fred L. Mohler*, 486.
Electron Relay, The Effect Produced upon Audion Characteristic Curves by Various Kinds of Signals (Buzzer, 60-Cycle A. C.), *A. D. Cole*, 331.
Electronic Frequency and Atomic Number, *Paul D. Foote*, 487.
Emission Velocity, Some Preliminary Results in a Determination of the Maximum, of the Photoelectrons from Metals at X-Ray Frequencies, *Kang-Fuh Hu*, 505.
Emulsions: (*a*) A New Method for Making Emulsions. (*b*) Properties of Emulsions, *Wheeler P. Davey*, 138.

Energy Partition, A General Theory of, with Applications to Quantum Theory, *Richard C. Tolman*, 261.
Equilibrium, On, under Non-Hydrostatic Stress, *P. W. Bridgman*, 180.
Erratum, 508.
Evaporimeter, A Self-Recording, *Alexander McAdie*, 147.

F.

Fenner, Clarence N., Methods of Temperature-Control in Glass-Melting Furnaces, 141.
Fluorescence, On the Thermodynamics of, *E. H. Kennard*, 29.
Fluorescence, A Study of the, of Certain Uranyl Salts at Room Temperature, *Frances G. Wick*, 100.
Fluorescence, On the Unpolarized, and Absorption of Four Double Chlorides of Uranyl, *Edward L. Nichols* and *H. L. Howes*, 285.
Foote, Paul D., The Resonance and Ionization Potentials for Electrons in Thallium Vapor, 486.
Foote, Paul D., Electronic Frequency and Atomic Number, 487.
Forsythe, W. E., Note on a Comparison of High-Temperature Scales, 139.
Freud, B. B., The Determination of Organic Compounds by an Optical Method, 249.

G.

Gallium, Note on the Grating Space of Calcite and the X-Ray Spectrum of, *Arthur H. Compton*, 430.
Gas Molecules. Elasticity of Impact of Electrons with, *J. M. Benade* and *K. T. Compton*, 184.
Gaseous Ions, The Mobilities of, *Kia-Lok Yen*, 337.
Germann, Frank E. E., A New Hydrate of Uranium Nitrate; Uranium Nitrate 1-cositetrahydrate, 245.
Gray, Arthur W., The Influence of Temperature Upon the Crushing Strength of a Dental Amalgam, 154.
Gray, Arthur W., The Influence of Amalgamation Variables upon the Mercury Content and the Crushing Strength of a Dental Amalgam, 492.

H.

Hair Hygrographs, Comparative Accuracy of Whirled Psychrometer, Assmann Aspiration Psychrometer, Porous Cup Atmometers, Piche Evaporimeter Saturation Deficit Recorder, Open Water Surface Evaporimeter, and Dry and Wet Bulb Thermometers, *Alexander McAdie*, 152.
Hall, Edwin H., Theory of Thermal Conductivity in Metals, 329.
Harmonic Synthesizer, An, having Components of Incommensurable Period and any Desired Decrement, *William J. Raymond*, 479.
Hartman, L. W., The Visibility of Radiation in the Blue End of the Visible Spectrum, 327.
Heat Conductivities, Measurement of, of Metals at High Temperatures, *Robert W. King*, 149.
Hebb, T. C., The Ionization Potential of Mercury Vapor, 170.
Helmick, P. S., The Variation in the Blackening of a Photographic Plate with Time of Exposure, Total Energy Remaining Constant, 372.
High-Temperature Scales, Note on a Comparison of, *E. P. Hyde* and *W. E. Forsythe*, 139.
High Vacua, The Production and Measurement of, *J. E. Shrader* and *R. G. Sherwood*, 134.
Hollnagel, Herbert P., On the Residual Rays of Rock Salt, 135.
Hollnagel, H. P., Transparency of Certain Carbon Compounds to Waves of Great Length, 505.
Howes, H. L., On Certain Absorption Bands in the Spectra of the Uranyl Salts, 66.
Howes, H. L., On Certain Absorption Bands in the Spectra of the Uranyl Salts, 143.
Howes, H. L., On the Unpolarized Fluorescence and Absorption of Four Double Chlorides of Uranyl, 285.
Howes, H. L., Note on a Phosphorescent Calcite, 327
Howes, H. L., The Photo-Luminescence and Katho-Luminescence, of Calcite 485.
Hu, Kang-Fuh, Some Preliminary Results in a Determination of the Maximum Emission Velocity of the Photoelectrons from Metals at X-Ray Frequencies, 505.
Hu, Kang-Fuh, On the Critical Absorption and Characteristic Emission X-Ray Frequencies, 489.
Hu, Kang-Fuh, On the Relation between the K X-Ray Series and the Atomic Numbers of the Chemical Elements, 488.
Hyde, E. P., Note on a Comparison of High-Temperature Scales, 139.
Hydrogen, A New Formula for the Temperature Variation of the Specific Heat of, *Edwin C. Kemble*, 156.
Hydrogen, Mobility of Ions in Air, and Nitrogen, *Kia-Lok Yen*, 248.
Hydrogen, Effect of, on the Electrical Resistivity of Carbon, *T. Peczalski*, 363, 508.

I.

Ionization, A Correction in the Theory of, by Collision, *Jakob Kunz*, 246.
Ionization Potential, The, of Mercury Vapor, *T. C. Hebb*, 170.
Ionization Potentials, The Resonance and, for Electrons in Thallium Vapor, *Paul D. Foote* and *Fred L. Mohler*, 486.

Ionization, The Theory of, by Collision. IV. Cases of Elastic and Partially Elastic Impact, *K. T. Compton* and *J. M. Benade*, 234.
Ions, Mobility of, in Air, Hydrogen, and Nitrogen, *Kia-Lok Yen*, 248.
Impact. The Theory of Ionization by Collision. IV. Cases of Elastic and Partially Elastic, *K. T. Compton* and *J. M. Benade*, 234.
Image Formation, The Geometry of, in X-Ray Analysis, *Horace Scudder Uhler*, 1.
Intensities, The Ratio of the, of the D Lines of Sodium, *Vivian Voss*, 21.
Iron, The Magnetization of, in the Absence of Hysteresis, *Winthrop R. Wright*, 161.

J.

Jones, Arthur Taber, Rotation of the Pulley in Melde's Experiment, 150.

K.

K X-Ray Series, On the Relation between the, and the Atomic Numbers of the Chemical Elements, 488.
Kahler, H., The Spectral Photoelectric Sensibility of Molybdenite, 497.
Katho-Luminescence, The Photo-Luminescence and, of Calcite. *E. L. Nichols, H. L. Howes* and *D. T. Wilber*, 485.
Kathodo-Fluorescence of Crystals, *Thomas B. Brown*, 39.
Kemble, Edwin C., A New Formula for the Temperature Variation of the Specific Heat of Hydrogen, 156.
Kennard, E. H., On the Thermodynamics of Fluorescence, 29.
King, Robert W., Measurement of Heat Conductivities of Metals at High Temperatures, 149.
Knudsen's Equations, Further Verification of, for Resistance to Molecular Flow, *L. E. Dodd*, 242.
Kunz, Jakob, Bohr's Atom, Zeeman's Effect and the Magnetic Properties of the Elements, 153.
Kunz, Jakob, A Correction in the Theory of Ionization by Collision, 246.

L.

Light, An Experimental Demonstration of the Constancy of the Velocity of, Reflected by a Moving Mirror, *Q. Majorana*, 411.
Long, M. B., The Spectral Photoelectric Sensibility of Molybdenite, 497.
Luminescence, A Preliminary Study of the, of the Uranyl Salts under Cathode Ray Excitation, *Frances G. Wick* and *Louise S. McDowell*, 421.
Lyle, F. W., The Breakdown Effort in Boron Conductors, 253.

M.

McAdie, Alexander, A Self-Recording Evaporometer, 147.
McAdie, Alexander, An Instrument for Continuously Recording the Percentage of Saturation and the Weight of the Water Vapor per Unit Volume in the Free Air, 148.
McAdie, Alexander, Comparative Accuracy of Whirled Psychrometer, Assmann Aspiration Psychrometer, Porous Cup Atmometers, Hair Hygrographs, Piche Evaporimeter Saturation Deficit Recorder, Open Water Surface Evaporimeter, and Dry and Wet Bulb Thermometers, 152.
McDowell, Louise S., A Preliminary Study of the Luminescence of the Uranyl Salts under Cathode Ray Excitation, 421.
Magnetic Moment, The Moment of Momentum Accompanying, in Iron and Nickel, *John Q. Stewart*, 100.
Magnetic Particle, The Nature of the Ultimate, *Arthur H. Compton* and *Oswald Rognley*, 132.
Magnetic Properties, Bohr's Atom, Zeeman's Effect and the, of the Elements, *Jakob Kunz*, 153.
Magnetization, The, of Iron in the Absence of Hysteresis, *Winthrop R. Wright*, 161.
Majorana, Q., On the Second Postulate of the Theory of Relativity: An Experimental Demonstration of the Constancy of the Velocity of Light Reflected by a Moving Mirror, 411.
Mathematical Tables, Report on the Construction of Certain, *C. E. Van Orstrand*, 332.
Megaphone, A, with a Rectangular Aperture, *F. R. Watson*, 244.
Melde's Experiment, Rotation of the Pulley in, *Arthur Taber Jones*, 150.
Mercury Content, The Influence of Amalgamation Variables upon the, and the Crushing Strength of a Dental Amalgam. Arthur W. Gray and Paris T. Carlisle, Fourth, 492.
Mercury Droplets, The Use of, in Milikan's Experiment, *John B. Derieux*, 203.
Mercury Droplets, Photoelectric Effects on, *John B. Derieux*, 276.
Mercury Vapor. The Ionization Potential of, *T. C. Hebb*, 170.
Meteor Train Spectra and Probable Erroneous Conclusions of the Observers, *C. C. Trowbridge*, 484.
Miller, Dayton C., The Influence of Amplitude of Electromagnetic Driving on the Frequency of Tuning Forks, 497.
Millikan's Experiment, The Use of Mercury Droplets in, *John B. Derieux*, 203.
Minor, Ralph S., Thermo-couples for Student Use in Calorimetric Work, 479.

Mobilities, The, of Gaseous Ions, *Kia-Lok Yen*, 337.
Moffitt, G. W., Complete Achromatization of a Two-Piece Lens, 144.
Mohler, Fred L., Resonance Radiation of Ssodium Vapor Excited by One of the D Lines, 70.
Mohler, Fred L., The Resonance and Ionization Potentials for Electrons in Thallium Vapor, 486.
Molybdenite, The Spectral Photoelectric Sensibility of, *W. W. Coblentz, M. B. Long* and *H. Kahler*, 497.
Momentum, The Moment of, Accompanying Magnetic Moment in Iron and Nickel, *John Q. Stewart*, 100.
Moving Mass, Is a, Retarded by the Reaction of its Own Radiation?, *Leigh Page*, 376.

N.

Nathanson, J. B., The Optical Properties of Rubidium, 227.
Nathanson, J. B., The Optical Properties of Rubidium, 333.
New Books, 159, 251, 335.
Nichols, E. L., On the Unpolarized Fluorescence and Absorption of Four Double Chlorides of Uranyl, 285.
Nichols, E. L., Note on a Phosphorescent Calcite, 327.
Nichols, E. L., The Photo-Luminescence and Katho-Luminescence of Calcite, 485.
Nitrogen, Mobility of Ions in Air, Hydrogen and, *Kia-Lok Yen*, 248.

O.

Opaque Crystals, The Analysis of Polarized Light from Small, *LeRoy D. Weld*, 249.
Optical Method, The Determination of Organic Compounds by an, *Thomas E. Doubt* and *B. B. Freud*, 249.
Optical Properties, The, of Rubidium, *J. B. Nathanson*, 227.
Optical Properties, The, of Rubidium, *J. B. Nathanson*, 333.
Organic Compounds, The Determination of, by an Organic Method, *Thomas E. Doubt* and *B. B. Freud*, 249.

P.

Page, Leigh, Is a Moving Mass Retarded by the Reaction of its Own Radiation?, 376.
Peczalski, T., Effect of Hydrogen on the Electrical Resistivity of Carbon, 363, 508.
Phosphorescent Calcite, Note on a, E. L. Nichols and H. L. Howes, 327.
Photoelectric Effects on Mercury Droplets, *John B. Derieux*, 276.
Photoelectrons, Some Preliminary Results in a Determination of the Maximum Emission Velocity of the, from Metals at X-Ray Frequencies, *Kang-Fuh Hu*, 505.
Photographic Plate, The Variation in the Blackening of a, with Time of Exposure, Total Energy Remaining Constant, *P. S. Helmick*, 372.
Photo-Luminescence, The, and Katho-Luminescence of Calcite, *E. L. Nichols, H. L. Howes* and *D. T. Wilber*, 485.
Photo-Plate, Images on Silvered, *C. W. Waggoner*, 137.
Piche Evaporimeter, Comparative Accuracy of Whirled Psychrometer, Assmann Aspiration Psychrometer, Porous Cup Atmometers, Hair Hygrographs, Open Water Surface Evaporimeter, and Dry and Wet Bulb Thermometers, *Alexander McAdie*, 152.
Planck Radiation Law, The Necessary Physical Assumptions Underlying a Proof of the, *F. Russell v. Bichowsky*, 58.
Polarized Light, The Analysis of, Reflected from Small Opaque Crystals, *LeRoy D. Weld*, 249.
Porous Cup Atmometers, Comparative Accuracy of Whirled Psychrometer, Assmann Aspiration Psychrometer, Hair Hygrographs, Piche Evaporimeter, Saturation Deficit Recorder, Open Water Surface Evaporimeter, and Dry and Wet Bulb Thermometers, *Alexander McAdie*, 152.
Precision Method, A, for Producing Artificial Daylight, *Irwin G. Priest*, 502.
Priest, Irwin G., A Precision Method for Producing Artificial Daylight, 502.
Priest, Irwin G., The Law of Symmetry of the Visibility Function, 498.

Q.

Quantitative Study of Gases, A Method for the, in Metals, *H. M. Ryder*, 486.
Quantum Theory, A General Theory of Energy Partition with Applications to, *Richard C. Tolman*, 261.

R.

Radiation, The Visibility of, in the Blue End of the Visible Spectrum, *L. W. Hartman*, 327.
Rain Drops, On the Formation of Negatively Electrified, *Fernando Sanford*, 445.
Ray Analysis, A New Method of Positive, *A. J. Dempster*, 316.
Raymond, William J., An Harmonic Synthesizer having Components of Incommensurable Period and any Desired Decrement, 479.
Rectification of Alternating Current by the Corona, *J. W. Davis*, 243.
Relativity, Theory of, On the Second Postulate of the, An Experimental Demonstration of the Constancy of

the Velocity of Light Reflected by a Moving Mirror, *Q. Majorana*, 411.
Residual Rays, On the, of Rock Salt, *Herbert P. Hollnagel*, 135.
Resonance Radiation of Sodium Vapor Excited by One of the D Lines, *R. W. Wood* and *Fred L. Mohler*, 70.
Resonance, The, and Ionization Potentials for Electrons in Thallium Vapor, *Paul D. Foote* and *Fred L. Mohler*, 486.
Retina, The Brightness Sensibility of the, *Julian Blanchard*, 81.
Rock Salt, On the Residual Rays of, *Herbert P. Hollnagel*, 135.
Rognley, Oswald, The Nature of the Ultimate Magnetic Particle, 132.
Rotation of the Pulley in Melde's Experiment, *Arthur Taber Jones*, 150.
Rubidium, The Optical Properties of, *J. B. Nathanson*, 333.
Rubidium, The Optical Properties of, *J. B. Nathanson*, 227.
Ryder, H. M., A Method for the Quantitative Study of Gases in Metals, 486.

S.

Sanford, Fernando, On the Formation of Negatively Electrified Rain Drops, 445.
Saturation, An Instrument for Continuously Recording the Percentage of, and the Weight of the Water Vapor per Unit Volume in the Free Air, *Alexander McAdie*, 148.
Second Postulate, On the, of the Theory of Relativity: An Experimental Demonstration of the Constancy of the Velocity of Light Reflected by a Moving Mirror, *O. Majorana*, 411.
Sensibility, The Brightness, of the Retina, *Julian Blanchard*, 81.
Sherwood, R. G., The Production and Measurement of High Vacua, 134.
Sherwood, R. G., Vacuum Gauges of the Radiometer Type, 241.
Shimizu, Takeo, The Relation between the General X-Radiation and the Atomic Number of the Target, 491.
Shrader, J. E., The Production and Measurement of High Vacua, 134.
Sodium Vapor, Resonance Radiation of, Excited by One of the D Lines, *R. W. Wood* and *Fred L. Mohler*, 70.
Specific Heat, A New Formula for the Temperature Variation of the, of Hydrogen, *Edwin C. Kemble*, 156.
Spectra, On Certain Absorption Bands in the, of the Uranyl Salts, *H. L. Howes*, 66.
Spectral Photoelectric Sensibility of Molybdenite, The, *W. W. Coblentz, M. B. Long* and *H. Kahler*, 497.
Stewart, John Q., The Moment of Momentum Accompanying Magnetic Moment in Iron and Nickel, 100.
Stress, On Equilibrium under Non-Hydrostatic, *P. W. Bridgman*, 180.
Structure, The Mathematical, of Band Series II., *Raymond T. Birge*, 136.
Surface Evaporimeter, Comparative Accuracy of Whirled Psychrometer, Assmann Aspiration Psychrometer, Porous Cup Atmometers, Hair Hygrographs, Piche Evaporimeter Saturation Deficit Recorder, Open Water, and Dry and Wet Bulb Thermometers, *Alexander McAdie*, 152.

T.

Temperature, The Influence of, Upon the Crushing Strength of a Dental Amalgam, *Arthur W. Gray* and *Paris T. Carlisle, 4th*, 154.
Temperature-Control, Methods of, in Glass-Melting Furances, *Clarence N. Fenner*, 141.
Thallium Vapor, The Resonance and Ionization Potentials for Electrons in, *Paul D. Foote* and *Fred L. Mohler*, 486.
Thermal Conductivity, Theory of, in Metals, *Edwin H. Hall*, 329.
Thermo-couples for Student Use in Calorimetric Work, *Ralph S. Minor*, 479.
Thermodynamics, On the, of Fluorescence, *E. H. Kennard*, 29.
Thermometers, Comparative Accuracy of Whirled Psychrometer, Assmann Aspiration Psychrometer, Porous Cup Atmometers, Hair Hygrographs, Piche Evaporimeter Saturation Deficit Recorder, Open Water Surface Evaporimeter, and Dry and Wet Bulb, *Alexander McAdie*, 152.
Tolman, Richard C., A General Theory of Energy Partition with Applications to Quantum Theory, 261.
Transparency of Certain Carbon Compounds to Waves of Great Length, *H. P. Hollnagel*, 505.
Tribolium Confusum, Increase in Length of Life of, *Wheeler P. Davey*, 493.
Trowbridge, C. C., Photograph of an Aurora Model, 482.
Trowbridge, C. C., On the Observation of the Apparent Focus of Auroral Streamers, 483.
Trowbridge, C. C., Meteor Train Spectra and Probable Erroneous Conclusions of the Observers, 484.
Tungsten, Young's Modulus of Drawn, and its Variation with Change of Temperature, including a Determination of the Coefficient of Expansion, *H. L. Dodge*, 311.
Tungsten X-Ray Spectrum, Wave-Lengths of the, *Elmer Dershem*, 461.

U.

Uhler, Horace Scudder, The Geometry of Image Formation in X-Ray Analysis, 1.

Ulrey, Clayton T., An Experimental Investigation of the Energy in the Continuous X-Ray Spectra of Certain Elements, 401.
Uranium Nitrate; A New Hydrate of, Uranium Nitrate Icositetrahydrate, *Frank E. E. Germann*, 245.
Uranium Nitrate Icositetrahydrate, A New Hydrate of Uranium Nitrate, *Frank E. E. Germann*, 245.
Uranyl, On the Unpolarized Fluorescence and Absorption of Four Double Chlorides of, *Edward L. Nichols* and *H. L. Howes*, 285.
Uranyl Salts, On Certain Absorption Bands in the Spectra of the, *H. L. Howes*, 66.
Uranyl Salts, A Study of the Fluorescence of Certain, at Room Temperature, *Frances G. Wick*, 100.
Uranyl Salts, On Certain Absorption Bands in the Spectra of the, *H. L. Howes*, 143.
Uranyl Salts, A Preliminary Study of the Luminescence of the, under Cathode Ray Excitation, *Frances G. Wick* and *Louise S. McDowell*, 421.

V.

Van Orstrand, C. E., Report on the Construction of Certain Mathematical Tables, 332.
Vacuum Gages of the Radiometer Type, *R. C. Sherwood*, 241.
Velocity, Variation of, of Waves, due to Motion of the Source, *Dinsmore Alter*, 481.
Visible Spectrum, The Visibility of Radiation in the Blue End of the, *L. W. Hartman*, 327.
Visibility Function, The Law of Symmetry of the, *Irwin G. Priest*, 498.
Voss, Vivian, The Ratio of the Intensities of the D Lines of Sodium, 21.

W.

Waggoner, C. W., Images on Silvered Photo-Plate, 137.
Water Vapor, An Instrument for Continuously Recording the Percentage of Saturation and the Weight of the, per Unit Volume in the Free Air, *Alexander McAdie*, 148.
Watson, F. R., A Megaphone with a Rectangular Aperture, 244.
Weld, Leroy D., The Analysis of Polarized Light Reflected from Small Opaque Crystals, 249.
Whirled Psychrometer, Comparative Accuracy of, Assmann Aspiration Psychrometer, Porous Cup Atmometers, Hair Hygrographs, Piche Evaporimeter Saturation Deficit Recorder, Open Water Surface Evaporimeter, and Dry and Wet Bulb Thermometers, *Alexander McAdie*, 152.
Wick, Frances G., A Study of the Fluorescence of Certain Uranyl Salts at Room Temperature, 100.
Wick, Frances G., A Preliminary Study of the Luminescence of the Uranyl Salts under Cathode Ray Excitation, 421.
Wilber, D. T., The Photo-Luminescence and Katho-Luminescence of Calcite, 485.
Wood, R. W., Resonance Radiation of Sodium Vapor Excited by One of the D Lines, 70.
Wright, Winthrop R., The Magnetization of Iron in the Absence of Hysteresis, 161.

X.

X-Ray Concentrator, A Mono-Wave-Length, *Elmer Dershem*, 244.
X-Ray Emission, Characteristic, as a Function of the Applied Voltage, *Bergen Davis*, 433.
X-Ray Frequencies, On the Critical Absorption and Characteristic Emission, *William Duane* and *Kang-Fuh Hu*, 489.
X-Ray Frequencies, Some Preliminary Results in a Determination of the Maximum Emission Velocity of the Photoelectrons from Metals at, *Kang-Fuh Hu*, 505.
X-Radiation, The Relation between the General, and the Atomic Number of the Target, *William Duane* and *Takeo Shimizu*, 491.
X-Ray Spectra, An Experimental Investigation of the Energy in the Continuous, of Certain Elements, *Clayton T. Ulrey*, 401.
X-Ray Spectrum, Wave-Lengths of the Tungsten, *Elmer Dershem*, 244.
X-Ray Spectrum, Note on the Grating Space of Calcite and the, of Gallium, *Arthur H. Compton*, 430.
X-Ray Spectrum, Wave-Lengths of the Tungsten, *Elmer Dershem*, 461.

Y.

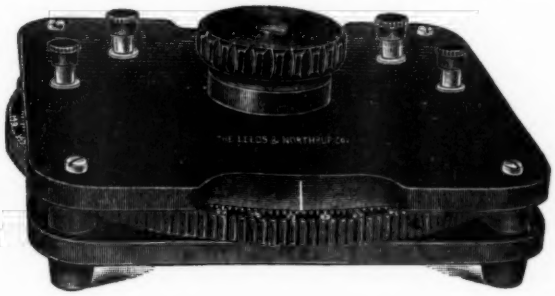
Yen, Kia-Lok, Mobility of Ions in Air, Hydrogen, and Nitrogen, 248.
Yen, Kia-Lok, The Mobilities of Gaseous Ions, 337.
Young's Modulus of Drawn Tungsten and its Variation with Change of Temperature, including a Determination of the Coefficient of Expansion, *H. L. Dodge*, 311.

Z.

Zeeman's Effect, Bohr's Atom, and the Magnetic Properties of the Elements, *Jakob Kunz*, 153.

Physics
Physics-LSA
Colmson
9-17-63
Replace

THE BROOKS' INDUCTOMETER



In the Brooks' Inductometer is offered a compact form of variable inductance, with a self inductance range of 5 to 50 millihenrys, possessing the following advantages:

1. A fair degree of astaticism, which tends to eliminate errors due to stray field effects.

2. It is less expensive and at the same time fully as accurate as the Ayrton-Perry instrument.

3. It occupies less space than the Ayrton-Perry form.

The instrument has a very nearly uniform scale, obtained by properly proportioning the coils.

It may be used as a mutual inductance.

It has a good ratio of maximum to minimum inductance (about 9 to 1) and also has as high a time constant as is consistent with good design and moderate size.

The instrument is fully described in Bulletin No. 152, a copy of which will be sent upon request.

THE LEEDS & NORTHRUP CO.

ELECTRICAL MEASURING INSTRUMENTS

4900 STENTON AVENUE PHILADELPHIA

THE PHYSICAL REVIEW

Information for Contributors.

1. All correspondence relating to contributions should be addressed to THE PHYSICAL REVIEW, Ithaca, N. Y. Manuscripts will be acknowledged as soon as received. Articles submitted for publication in the REVIEW are not to be submitted for publication elsewhere unless the authorization of the editors has been obtained, and, in case of duplicate publication in English, proper reference to the REVIEW is made. Manuscript should be ready for the printer; the editors cannot assume responsibility for its correctness. The presentation should be as concise as is consistent with clearness; all unnecessary duplication of data in tables and in curves is to be avoided, and tabular matter should be introduced *in extenso* only when the exact numerical values affect the value of the paper. It is requested that the metric system be used in all cases. Whenever the value of a quantity is expressed in any other system, its value in the metric system should be added in parentheses.

To insure prompt attention during the summer, manuscripts should be submitted by June 15.

2. Illustrations should be in black and white and should be ready for direct reproduction such illustrations will be made without expense to the author. The ink used in preparing illustrations should be *jet black*. Curves can be satisfactorily reproduced when plotted on plain paper or on blue-lined cross-section paper; co-ordinates may be ruled in black at desired ntervals, for example every centimeter or every inch. Blue lines are not reproduced photographically; *colors other than jet-black and blue should be avoided*. The material in an illustration should be compactly arranged; when it is much spread out, a greater reduction is necessary in reproduction. Lettering on illustrations should be plain and of sufficient size to be legible after reduction and should be complete (including designation of co-ordinates), requiring no printing from type except in the descriptive caption beneath.

It is generally desirable to refer to *all* illustrations as "figures," designated by one consecutive series of numbers. The location of each figure should be marked in the manuscript, together with any caption which is to be printed beneath it.

3. A proof of each contributed article will be sent to the author for his approval. It is requested that all proof be returned promptly. Authors should note that cross reference can not well be made by page number, for a change in paging is often necessary in the final make-up.

Although proof of abstracts can usually be submitted to authors, this is not always possible without delay in publication; in the case of abstracts, therefore, it is particularly important that the manuscript be free from error. In revising proof of abstracts, authors should correct any errors of the printer, but should make no changes that will affect the arrangement of paging.

4. Offprints, ordered on the proper form with return of proof, will be furnished by the printer according to the prices given below Any special instructions in regard to offprints,—special title page, etc.,—should be indicated on the order to the printer (or attached thereto) and not as a letter to the editors. (Further inquiries in regard to offprints may be addressed to The New Era Printing Co., Lancaster, Pa.)

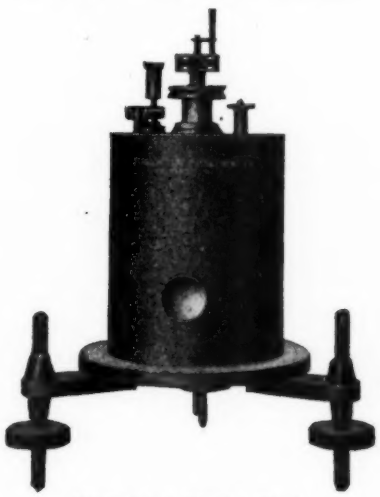
CHARGE FOR OFFPRINTS

Copies	4 pp.	8 pp.	12 pp.	16 pp	20 pp.	24 pp.	28 pp.	32 pp.	48 pp.	64 pp.
50	$1.45	$1.95	$2.60	$2.92	$3.67	$4.30	$5.20	$5 70	$8.10	$10.60
75	1.60	2.30	3.05	3.45	4.70	4.95	6.10	6.60	9.45	11.05
100	1.80	2.60	3.50	3.95	5.10	5.90	7.00	7.50	10.85	13.05
150	2.05	3.05	4.20	4.85	6.75	6.95	7.35	9.15	13.20	17.55
200	2.35	3.75	5.25	6.15	7.85	8.75	10.45	11.05	16.35	21.65
300	2.95	4.75	5.85	8.15	10.60	11.90	14.10	14.85	22.15	29.55

Covers: 50 covers for $1.00, and 1c. for each additional cover.

Prices subject to change on account of changing cost of paper.

COMPTON
QUADRANT
ELECTROMETER



Described in Circular No. 6

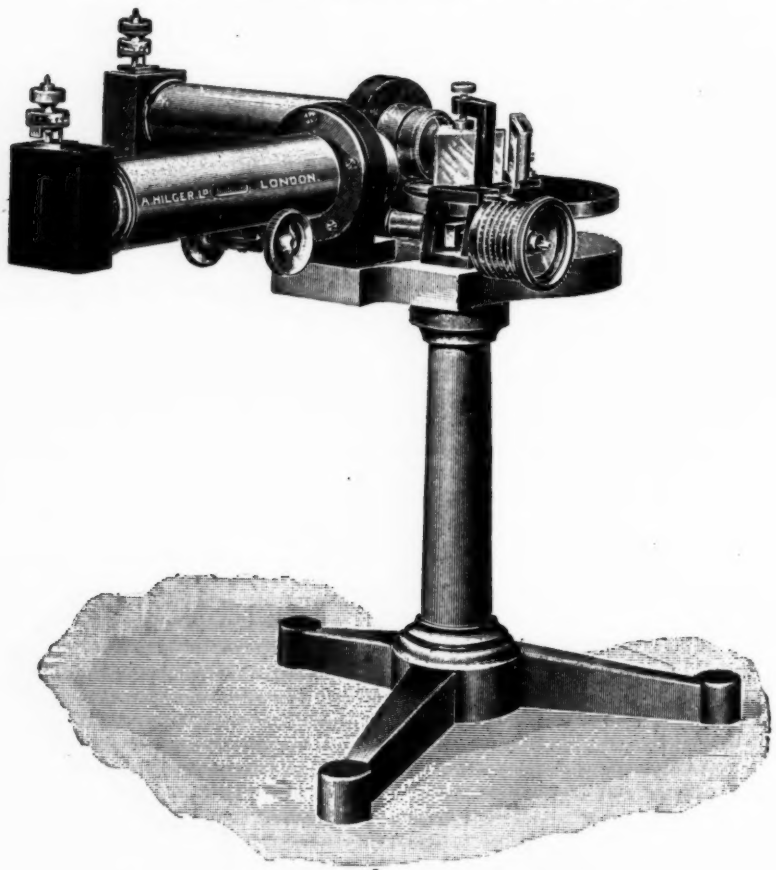
Pyrolectric Instrument Co.

Pyrometric and Electrical Precision Instruments
148 East State St. TRENTON, N. J.
E. F. Northrup, President and Technical Adviser

MONOCHROMATOR for the ULTRA-VIOLET

for experiments on the

PHOTO-ELECTRIC EFFECT, ETC.



Calibrated to read direct in Wavelengths

from 185$\mu\mu$ to 700$\mu\mu$.

Fittings for the INFRA-RED (range from 500$\mu\mu$ to 9000$\mu\mu$) can also be supplied for the above ; including prism of Rocksalt, and our new design of LINEAR THERMOPILE, etc., by means of which the instrument can be converted in a few minutes into an accurate Infra-Red Spectrometer reading direct in Wavelengths.

Full particulars post free on application to

ADAM HILGER, Ltd., 75A CAMDEN ROAD, LONDON N.W.

Telegraphic Address "Sphericity, London"
Western Union Code

THE CUTLER-HAMMER MFG. CO.

ELECTRIC CONTROLLING DEVICES

MILWAUKEE, WIS.

W. G. PYE & COMPANY

Scientific Instrument Makers

Granta Works — Cambridge, England

This is a very serviceable instrument, calibrated to read direct in maxwells: 1 Scale Division = 10,000 maxwells.

No. 8835 Fluxmeter $40.80.

No. 8837 Search coil 5 mm. diam. 10 Turns $6.00.

No. 8838 Search coil 10 mm. diam.: 10 Turns $6.00.

Descriptive Pamphlet upon Application.

A GOOD FLUXMETER AT A REASONABLE PRICE

(5)

GRAPHITE-SELENIUM CELLS

Fournier d'Albe's Pattern

Great Stability and High Efficiency

With a sensitive selenium surface of 5 sq. cm., and a voltage of 20, the additional current obtainable at various illuminations (in metre-candles) is:

At 1 m.c. . . .	**¼ milliamp**
At 50 m.c. . . .	**1 "**
At 500 m.c. . .	**2 "**

For particulars and prices apply to the SOLE AGENTS

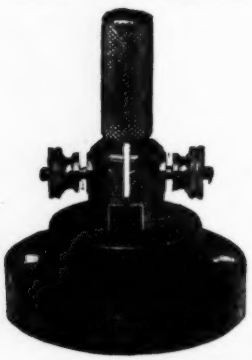
JOHN J. GRIFFIN & SONS LTD

Makers of Physical, Electrical & Scientific Instruments

KEMBLE ST. KINGSWAY LONDON, W. C.

Gambrells' Patent "Independent" Plug Contact

For Resistance Boxes, Wheatstone Bridges, Switches, etc., etc.



In use by H. M. Government, Leading Telegraph Companies, Cable Manufacturers, Electricity Works, etc., etc.

The only Resistance Box contact with plugs entirely independent of each other. One standard size, all plug caps interchangeable, independent of type of instrument. Large surface contact. No plug heads to give trouble. High insulation, each unit self assembling. Can be more quickly used.

GAMBRELL BROS., Ltd.

Makers of Galvanometers, Resistance Boxes, Potentiometers, etc.

Head Office and Works, MERTON ROAD, SOUTHFIELDS, LONDON, ENGLAND

A LIST OF ENGINEERING BOOKS

Did you know that we publish a list of Engineering books in Mechanical, Civil and Electrical Engineering, also on Architecture. You may not want to buy now but you may find in the list books that you will need. Write for a copy and keep it on hand.

WHY HAVE CROSS SECTION PAPER

Cross Section Paper shows the result of a large mass of figures in a very quick way. Still you will want to have accurate Cross Section paper so that when you make comparison of different curves their value may be more readily taken into account. Write for a copy of the Cross Section sample book. It shows actual samples of paper and printing.

Cornell Co-operative Society

Morrill Hall **Ithaca, New York**

Kunz Photo-Electric Cell

No. F3965

A Sensitive Detector of Light and Electric Waves

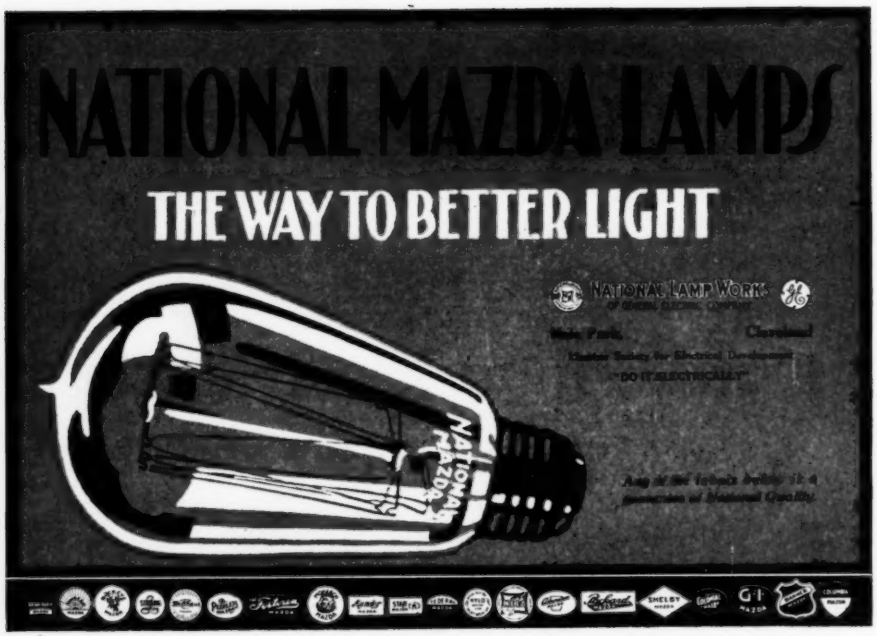
Can be used as a PHOTOMETER in stellar photometry, in plant physiology, and in photo-chemistry; for measurements of absorption, transmission, reflection and radiation of light; and as a DETECTOR of electric and optical signals. For a full description of the method of using it and its various applications, see Physical Review, 2nd Series, Vol. VII, No. 1; Vol. X, No. 2; Astro-Physical Journal, Vol. XLV, No. 3, for March, 1917.

Price - - - Net, $25.00

CENTRAL SCIENTIFIC COMPANY

460 EAST OHIO STREET **CHICAGO, U. S. A.**

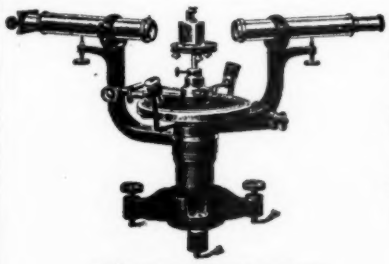
(Lake Shore Drive, Ohio and Ontario Sts.)


NATIONAL MAZDA LAMPS
THE WAY TO BETTER LIGHT
NATIONAL LAMP WORKS
OF GENERAL ELECTRIC COMPANY
Nela Park, Cleveland
"DO IT ELECTRICALLY"
NATIONAL MAZDA

MORSE TWIST DRILL & MACHINE COMPANY New Bedford, Mass.

Makers of Twist Drills, Reamers, Cutters, Etc.

TOOLS THAT PROVE THEIR WORTH.



Laboratory Spectrometers

SPECIALTIES

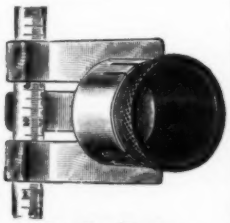
High Grade Measuring Instruments to cover all requirements

Laboratory and demonstration apparatus for advanced and elementary work

Full line Calorimeters

Universal Laboratory Supports

General Laboratory Supplies



Reading Device for Thermometers $1.80

WM. GAERTNER & CO., 5345-49 Lake Park Ave., Chicago

The Langmuir Condensation Pump

Dr. Irving Langmuir (of the General Electric Company) has developed an exceedingly interesting and valuable *high-speed, high-vacuum pump;* and by special arrangement with the makers, we are acting as sole distributors of this device for laboratory purposes.

As shown in accompanying illustration, the pump is manufactured entirely of metal; and thus is far more permanent in character than would be possible if glass were used.

Connections are provided for water cooling; and beneath the pump is a small electric heater (terminals not shown in picture) for attachment to 110 volt lighting circuit.

With the Langmuir Pump pressures as low as 10^{-6} bar have been obtained, and there is little doubt that very much lower pressures can be produced by cooling the bulb to be exhausted, in liquid air, so as to decrease the rate at which gases escape from the walls.

As is known to physicists, one "bar" is equal to 0.00075 mm. of mercury.

Some type of primary pump must be used; capable of developing vacuum not less than 0.1–0.15 mm. of mercury.

In the December 1916 issue of General Electric Review, Dr. Langmuir published a paper entitled—"The Condensation Pump, an Improved Form of High-Vacuum Pump." It should be read by all scientists who are interested in high-vacuum work. Write for a copy.

$90.00 is the net price for a Langmuir Condensation Pump

JAMES G. BIDDLE PHILADELPHIA

1211-13 Arch St.

Be sure to visit our Permanent Exhibit of Scientific Instruments

Special Educational Facilities

for employees of the

General Electric Company

Testing Section Devoted to Motors and Generators

General Electric Educational Facilities

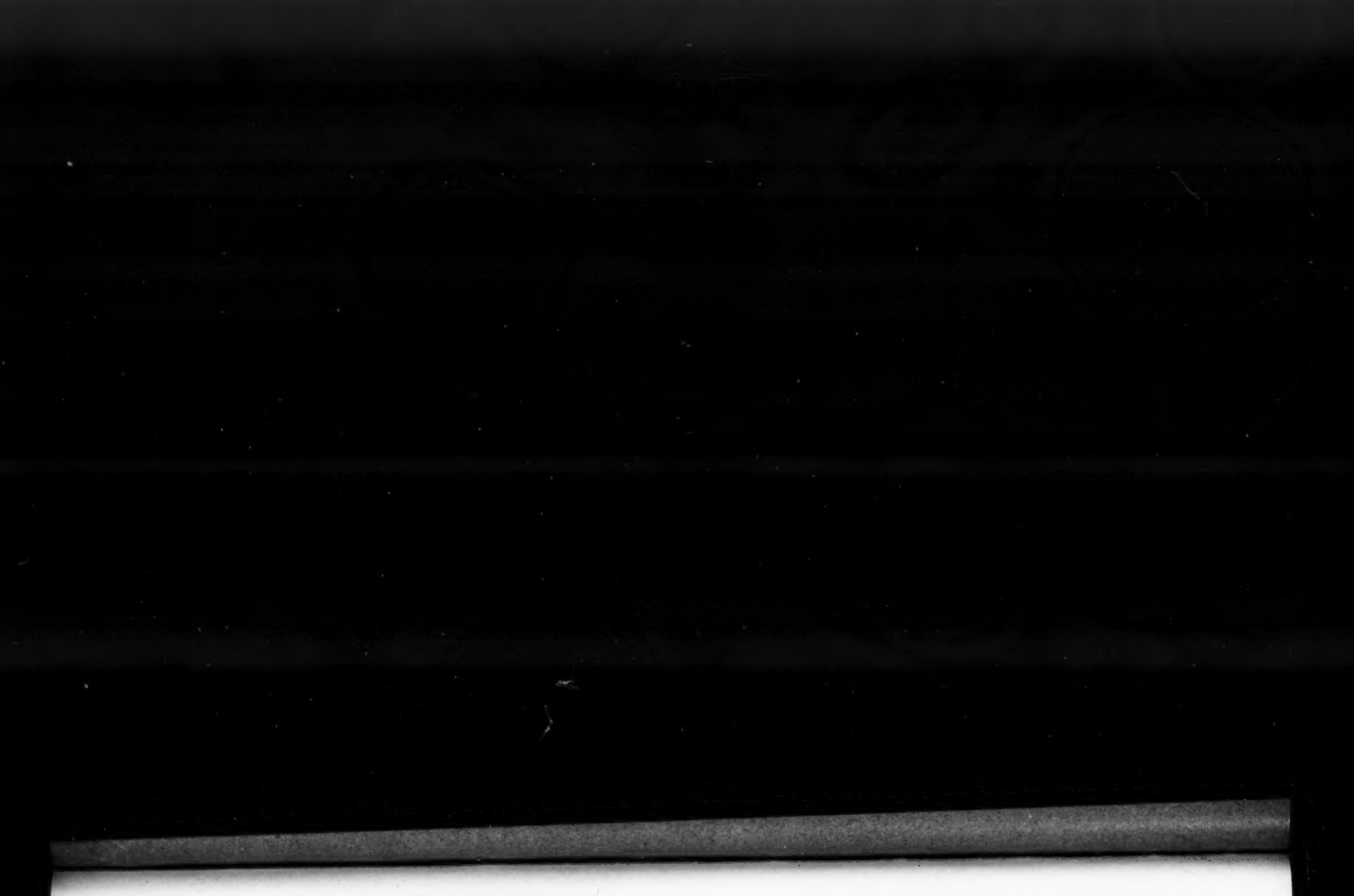
Apprentice Course
General Electric Vocational School
Testing Course for High School Graduates
Engineer's Testing Course for Technical Graduates
Advanced Work for Student Engineers
Engineering Lectures to Student Engineers
Department Lectures
American Institute of Electrical Engineers

The General Electric Company affords special facilities for each employee to obtain further intellectual training in any chosen profession, or occupation.

The electrical industry is replete with opportunities for young men who possess special knowledge, real ability, or the power of concentrated application in the study of their profession. The General Electric Company is never satisfied that its employees should follow merely a routine course of occupation and the accomplishment of a "day's work." The Company desires, and offers abundant opportunity, for every employee to fit himself for higher grades of service. It provides for study and application along lines which will increase an employee's earning capacity, usefulness and development.

General Electric Company

SCHENECTADY, N. Y.

Twelve large plants - - - - - - - - - 100,000 employees

95-24